B⋈Tree

A mechanism to drive existing B⁺Trees to do Join Internally.

B⋈TREE Index

To understand how B⋈TREE Index works let see what happens when we insert a new Row R_m from Table T_i into the database.

Suppose that table T_i is in Direct Join with a table T_k, we have to look for all the Rows $R_n \ldots R_z$ in T_k that satisfy the join condition with R_m and insert Rows references to $R_m R_n \ldots R_m R_z$ in the virtual table T_{ik}.

The process should be repeated for $R_m R_n \ldots R_m R_z$ with a table in join at least with one of the base tables constituting the Virtual Join Table T_{ij} and so on until we scan a path in the sequence of tables in join.

Transformation of Existing B+Tree

- The internal definition for the creation of a B+Tree take in consideration the following:
  - Name of B+Tree index follow by an index
  - Number of base tables constituting the virtual table indexed by the B+Tree
  - Length and type of Keys
  - Length and type of Inherited Keys (They are supplementary fields inserted in the B+Tree but they are not part of the key and they are not used for comparison)

- Declare the page of B+Tree as a buffer of bytes and divide it as needed. Many existing B+Tree follow this technique to support different type of multiple columns Key.

- The Leaf Page structure consists of:
  - Pointer to the previous sibling page
  - number of elements in which everyone consists of:
    - Space for the columns forming the keys
    - Space for the Data Pointers (Row Ids) to reference the Row in every table
    - Space for the columns forming the Inherited Keys
  - Pointer to the next sibling Page

Transformation of Existing B+Tree (continue)

- The Non Leaf Page structure consists of:
  - Pointer to a child page which key values are smaller than all the keys in the page
  - number of elements in which everyone consists of:
    - Space for the columns forming the keys
    - Pointer to a child page which key values are bigger than the keys in the Element

- Due to the fact that many join keys are duplicates, change has been made for the duplicates in the sense when 2 keys are equals, we consider the data references for them. The B+Tree keeps these possibly duplicated keys separate internally by combining the unique sequence of data references with each key. The process of combination is done logically, and requires no additional space for key storage.

Many advanced B+Tree in the market use (Key, Data Reference) combination to refer to unique Row eliminating duplicates internally and use additional fields others than the one forming the key to avoid access to the table.

So for those B+Trees, the only modification is instead of space of one Data Reference is a space for multiple Data Reference Space.

Definitions

- Base Table:

  Base tables are database objects whose structure and the data they contain are both on disk.

- Virtual Table:

  Virtual tables are tables whose contents are derived from base tables. Only its definition (base tables Names constituting it) is stored on disk.

Definitions

Direct Join:

Two tables are in Direct Join if there is a link between them (in other sense if there is common columns between them).

Join Graph:

A graph representing direct join between tables.

Adjacency List:

List for every table T_i in the database all those tables in direct Join with it.

Generating Join Graph

- Base Tables represent the vertexes of the Join Graph.
- Due to the fact that join is commutative, for every pair of tables in direct join between them as defined by DBA create an undirected edge to link them.
- It is very easy to knows which tables are in direct join with others tables from the definition of common columns between them.

The algorithm for generating the Linked List representation of the join Graph is the following:

generateJoinGraph (in BaseTables; out JoinGraph)

insert the base tables as vertexes of the graph

for every direct join between 2 tables T_i and T_k where T_i is the table of order i and T_k is the table of order k as defined by the DBA do

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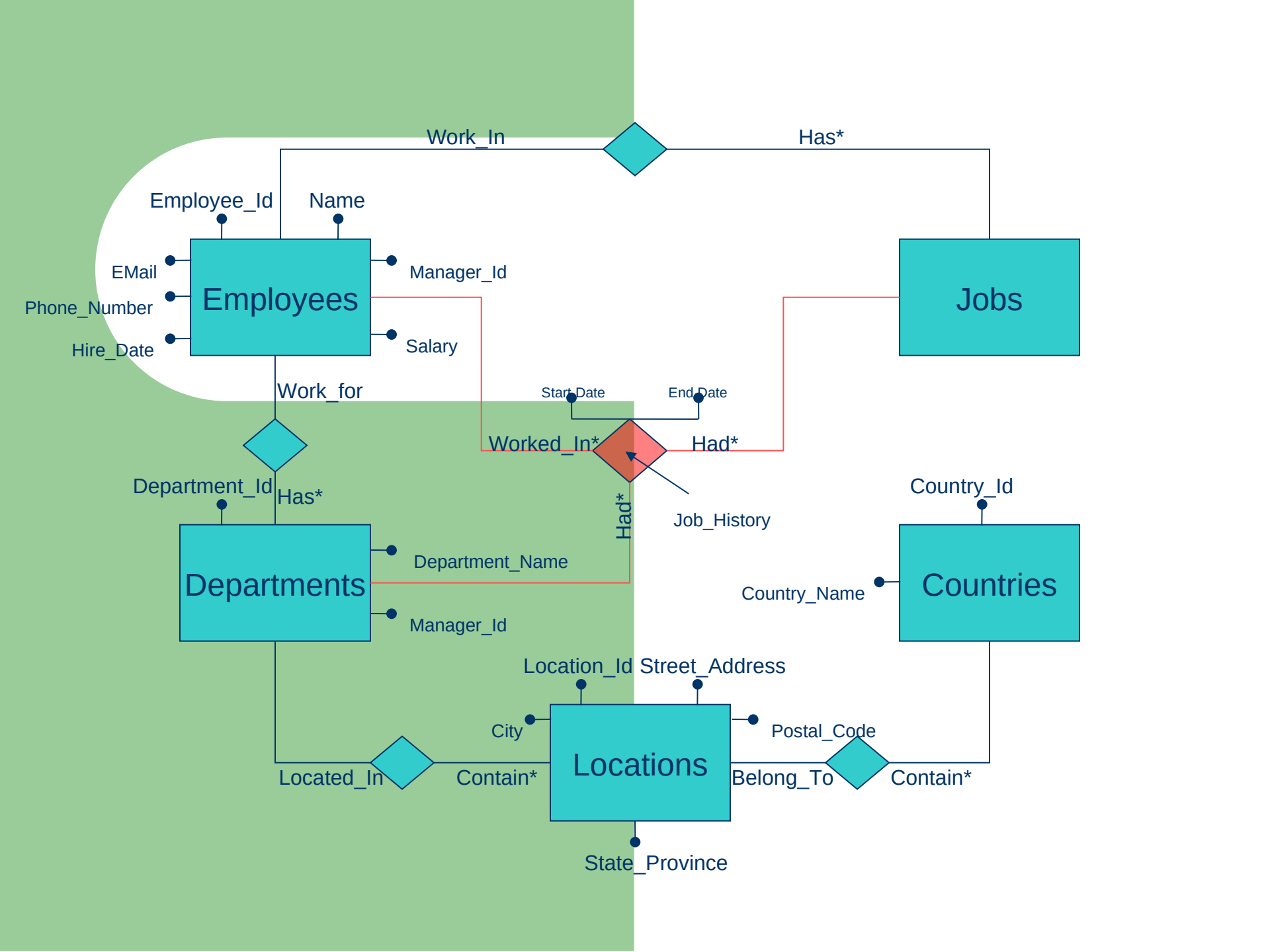
Work_In
Has*
Employee_Id
Name
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Phone_Number
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Jobs
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End_Date
Worked_In*
Had*
Department_Id
Has*
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Base Tables

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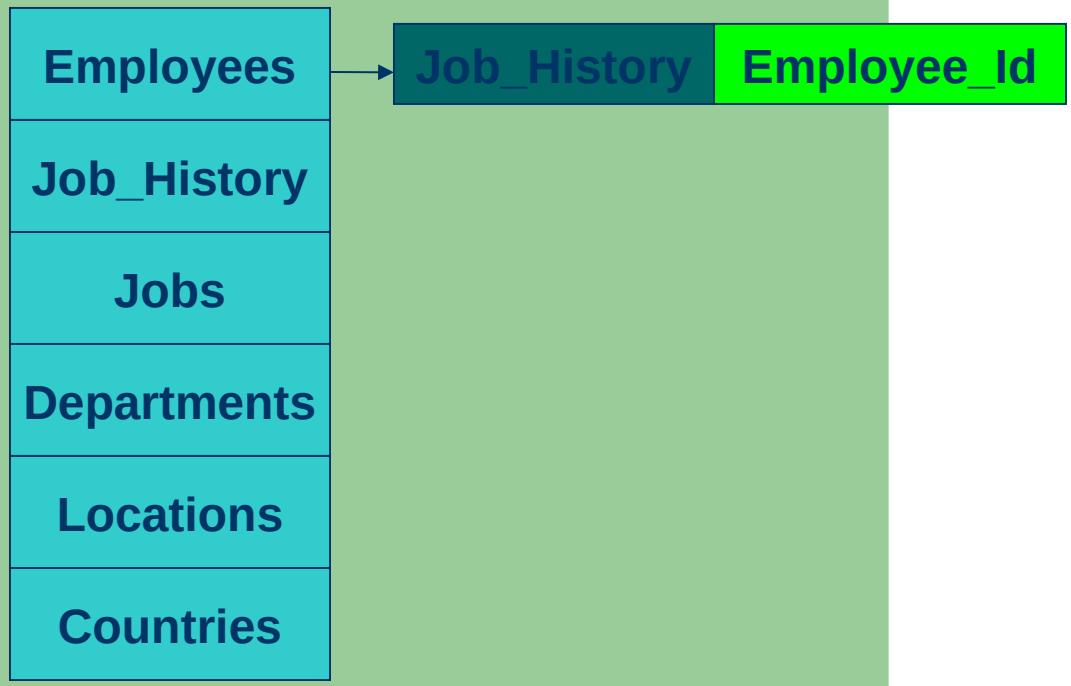

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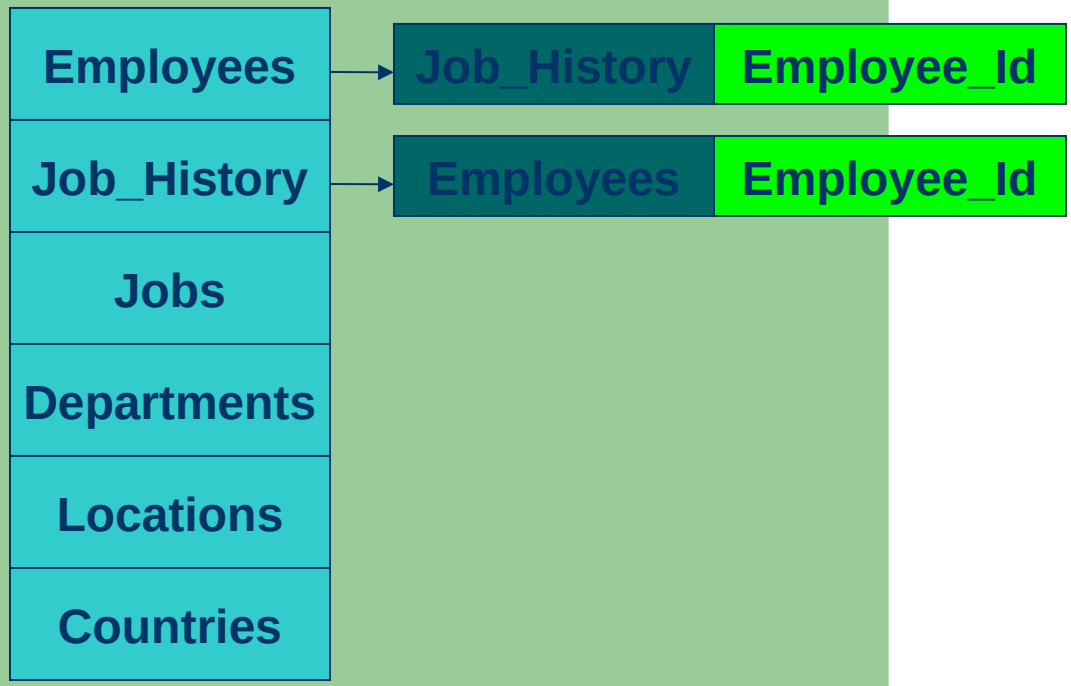

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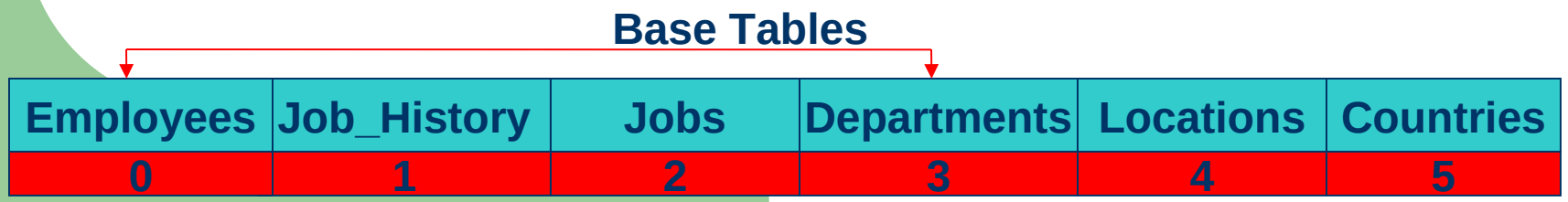

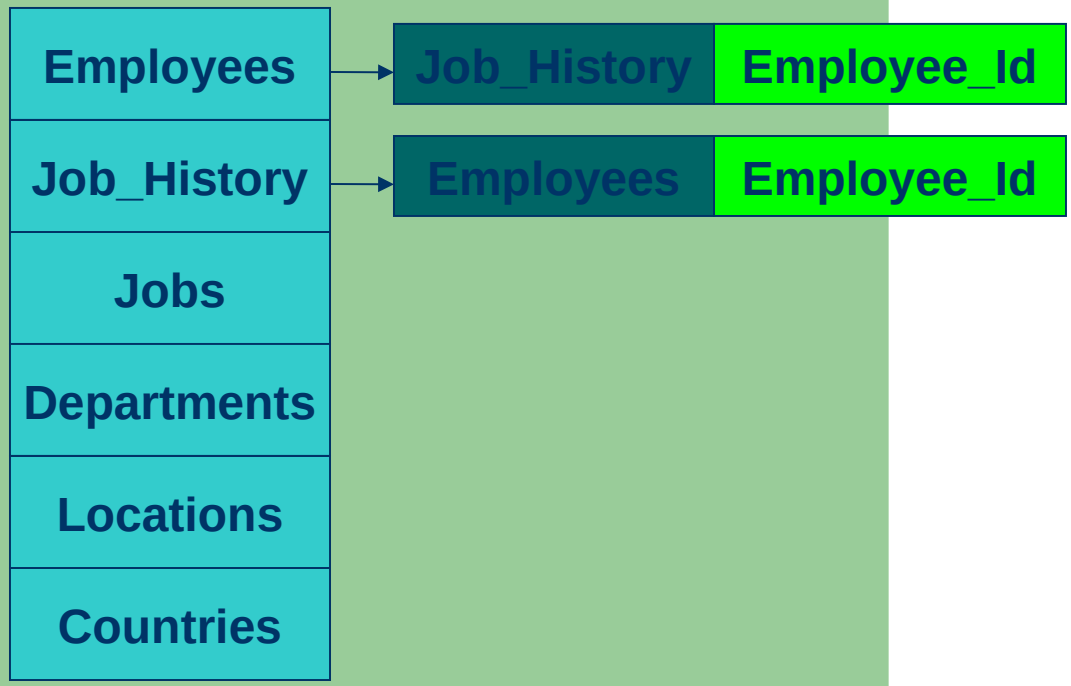

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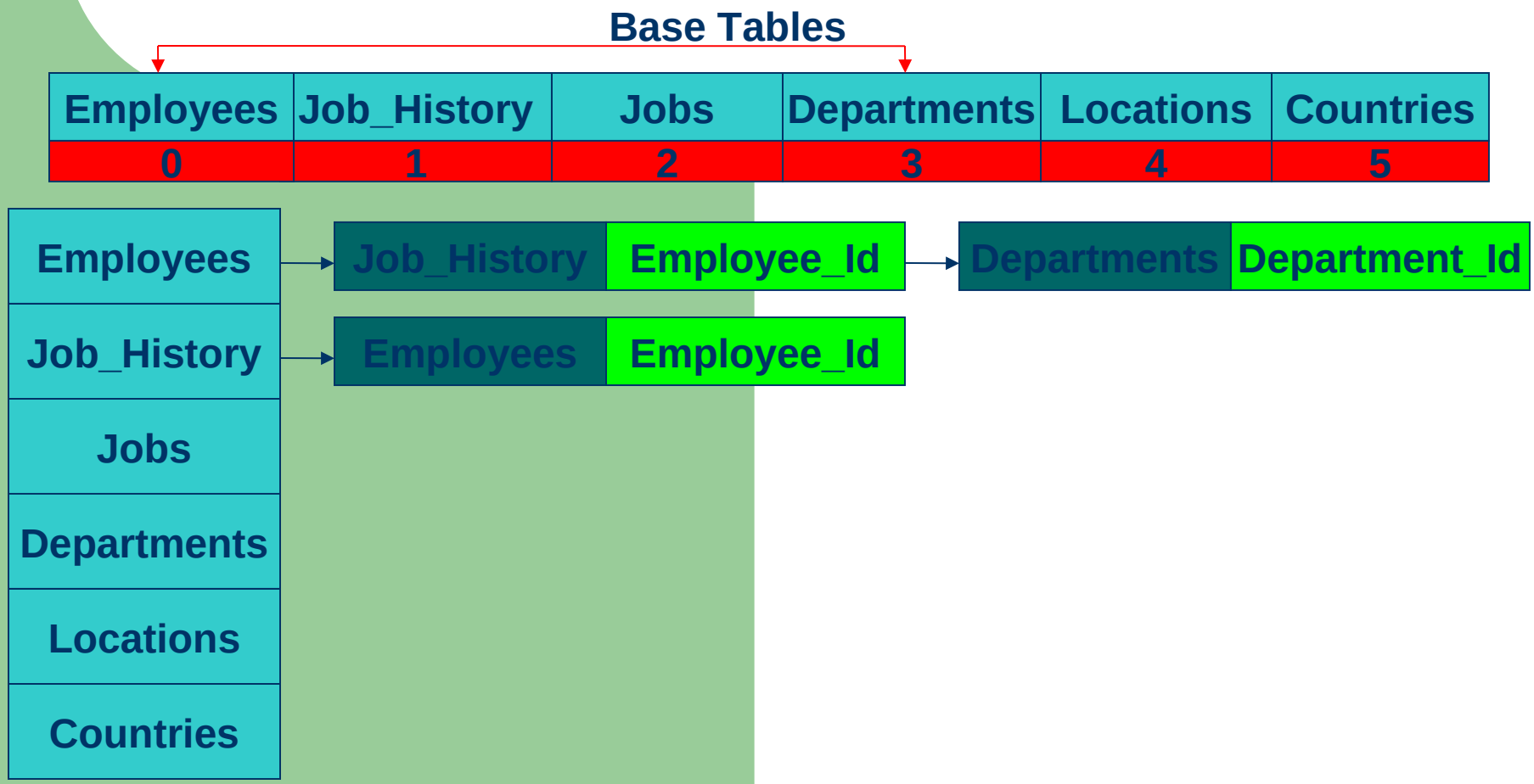

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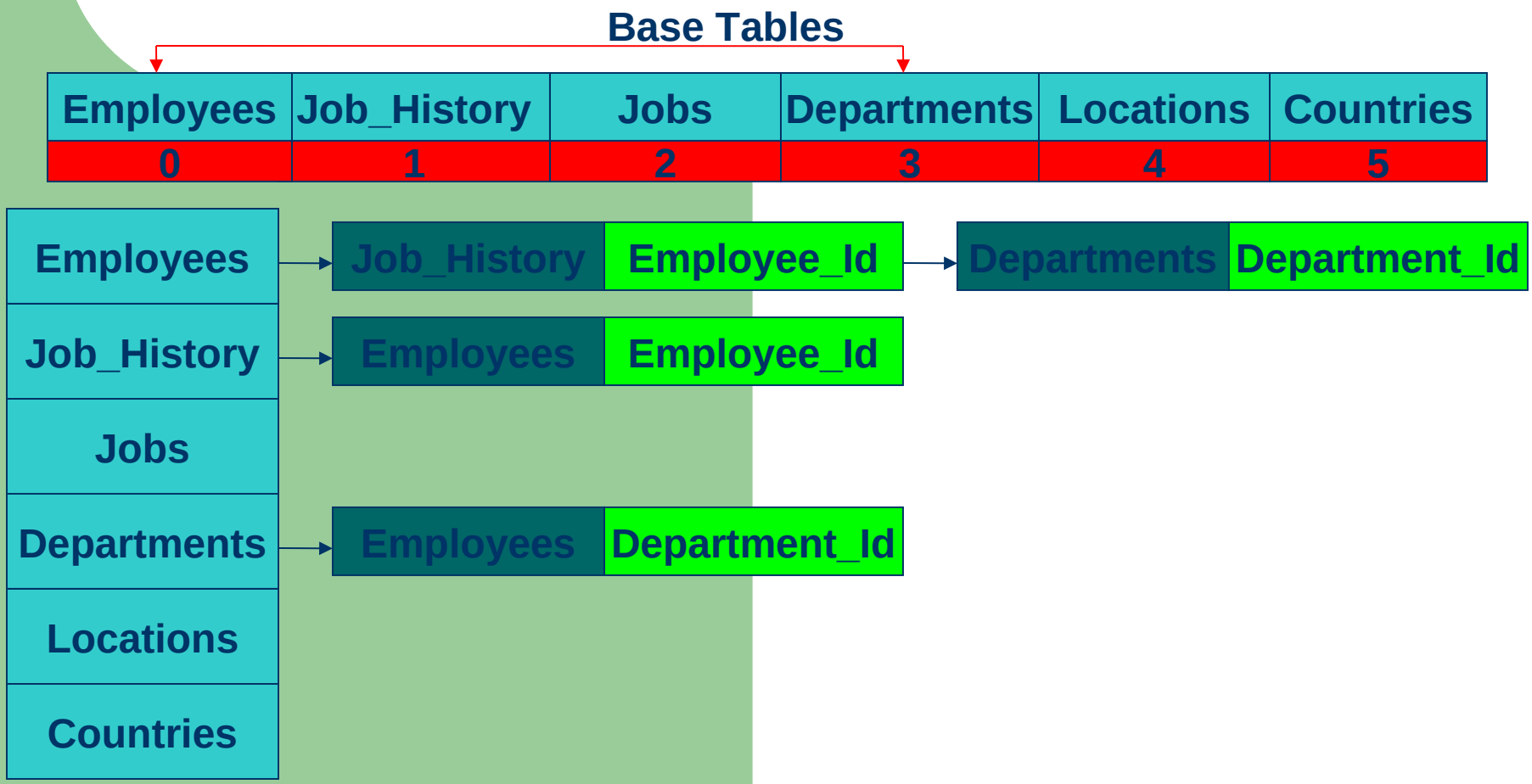

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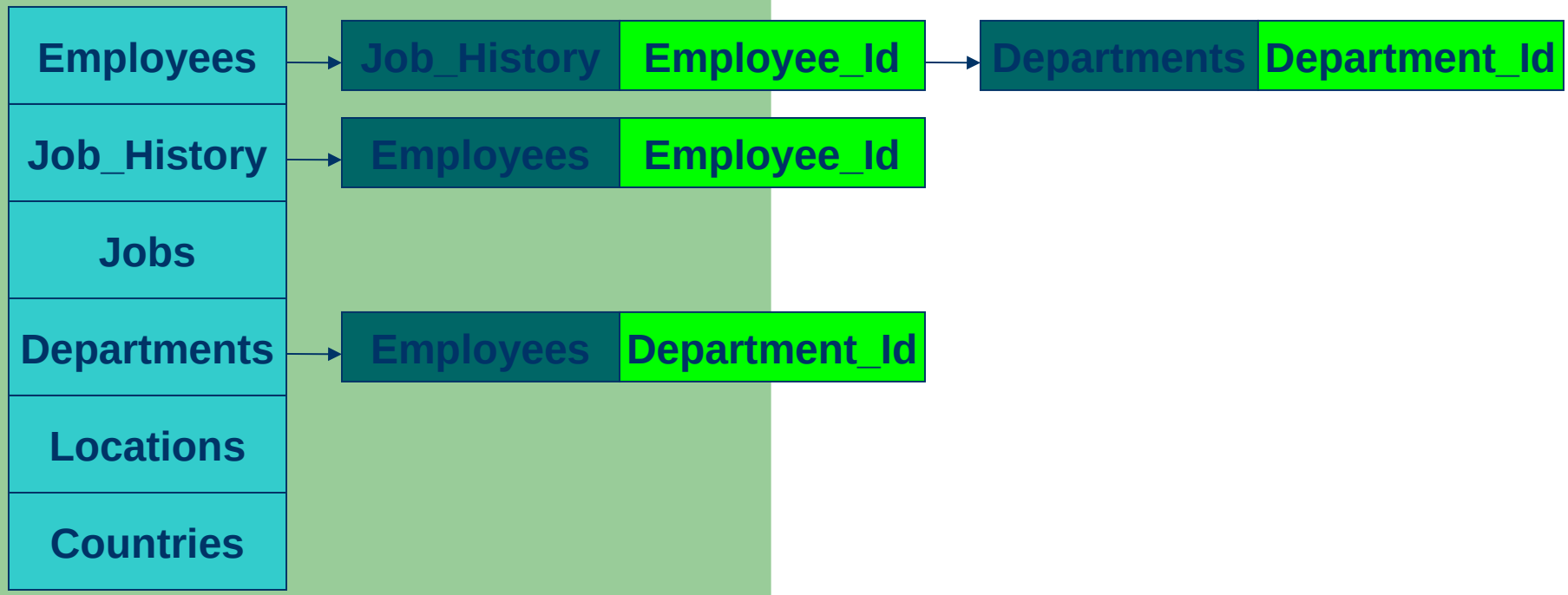

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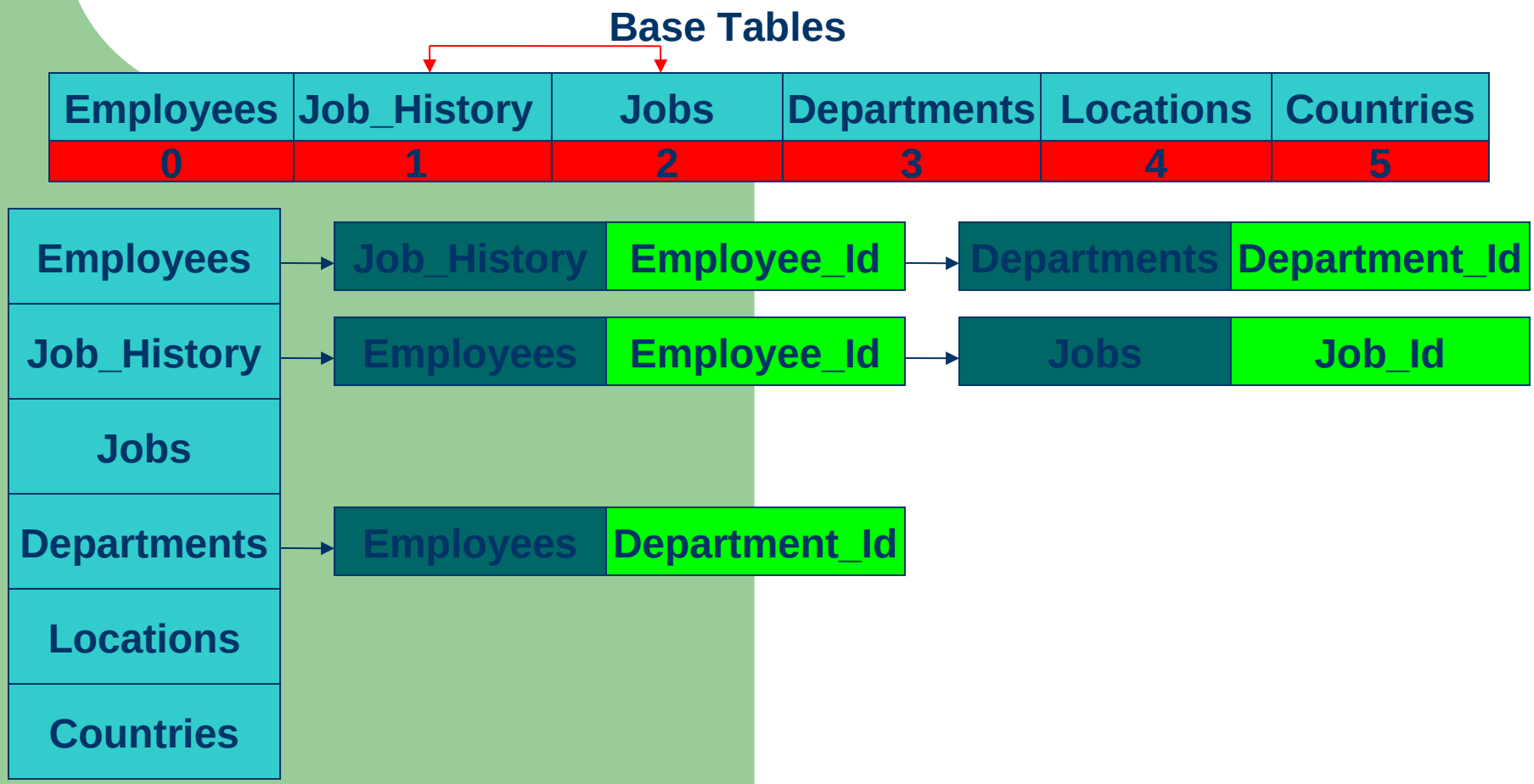

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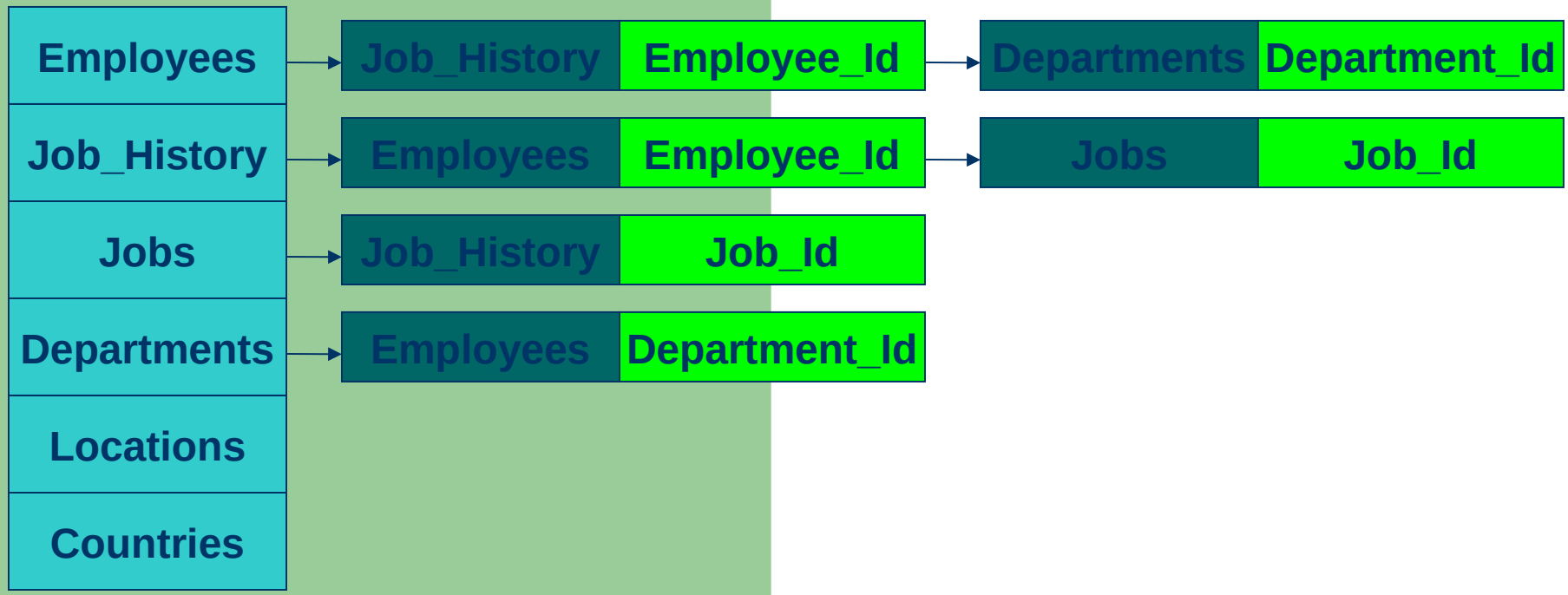

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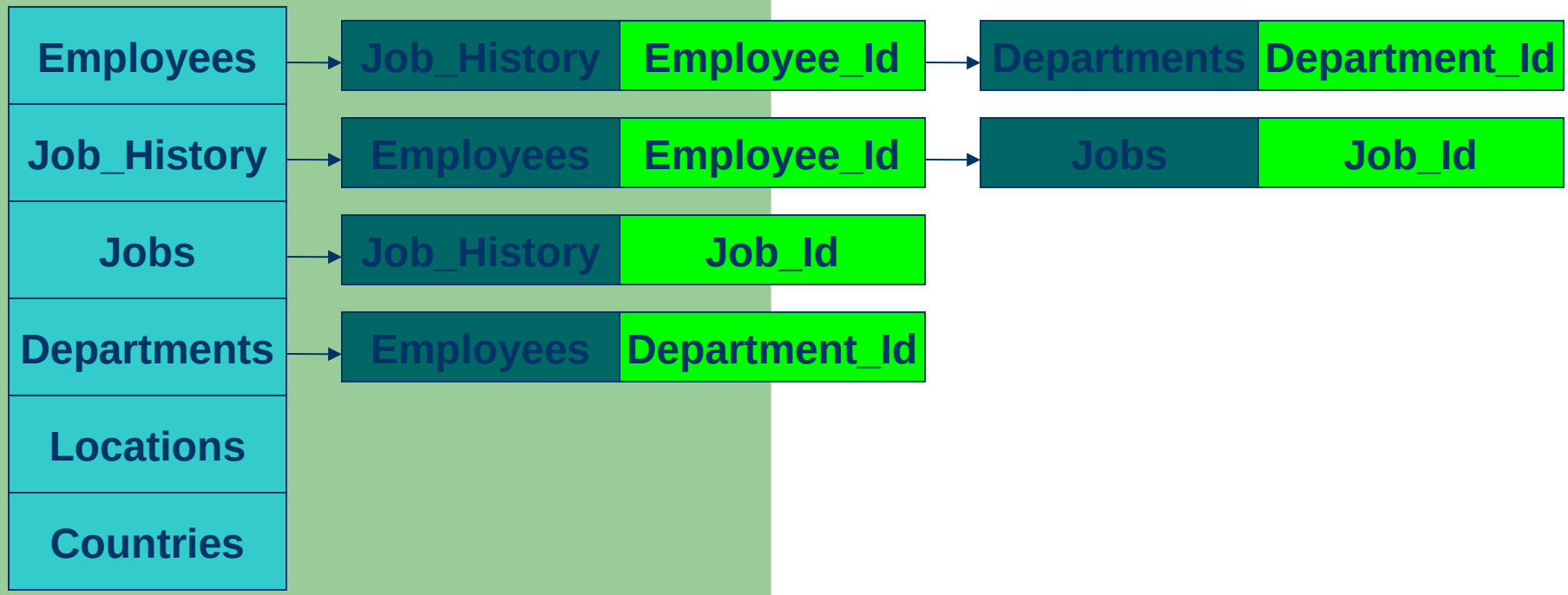

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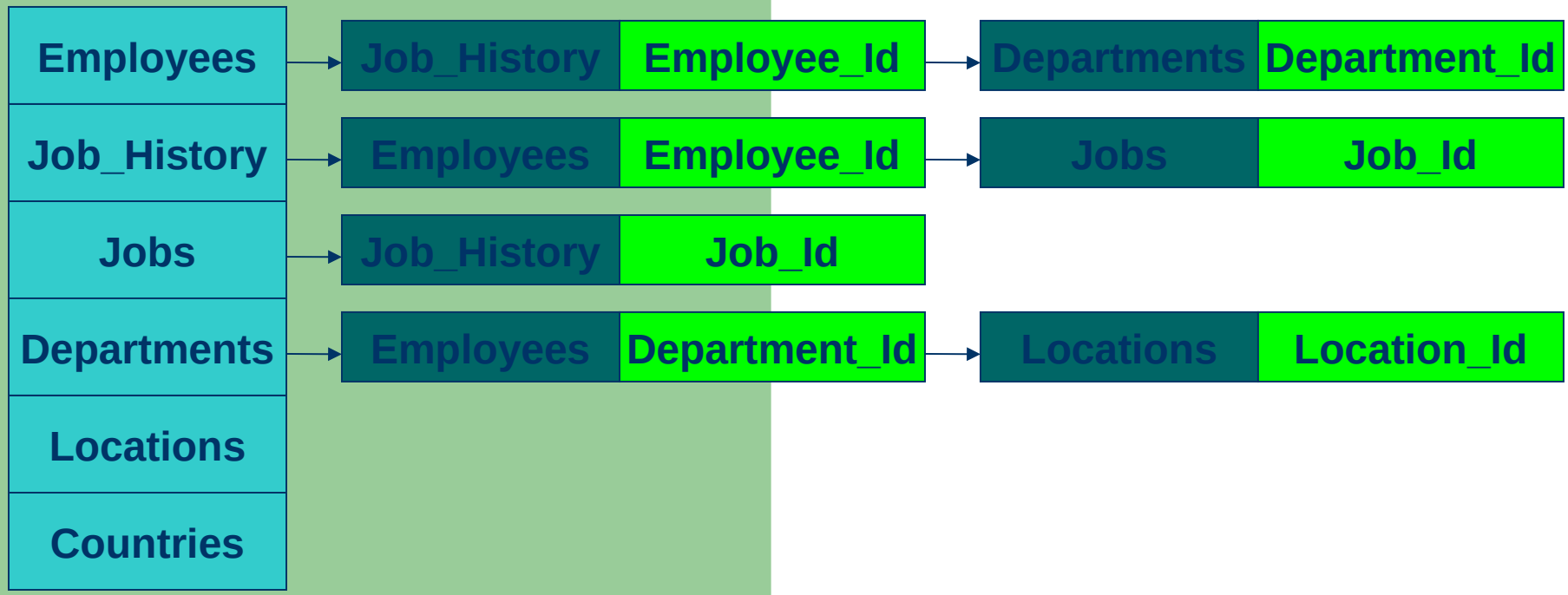

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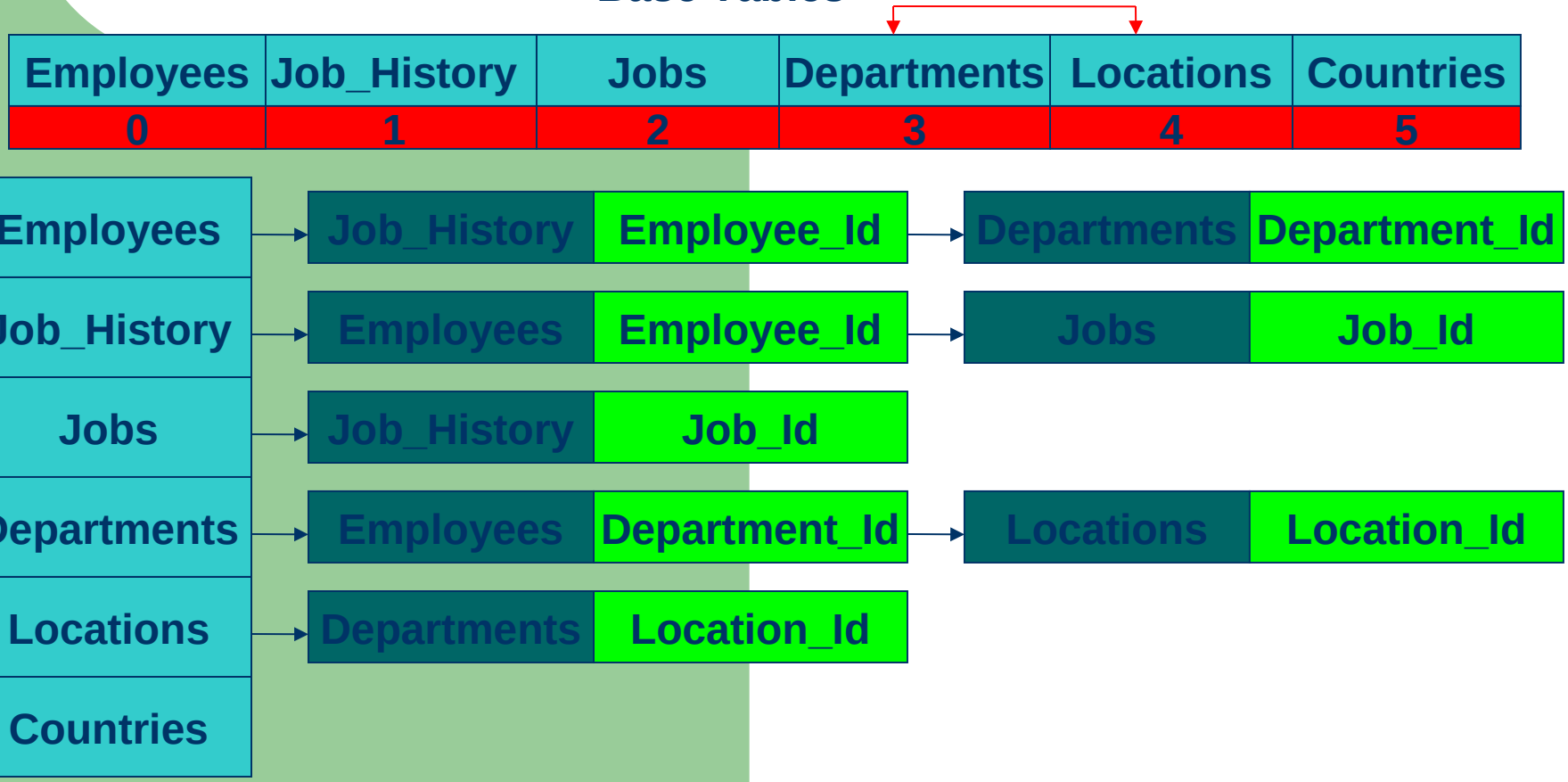

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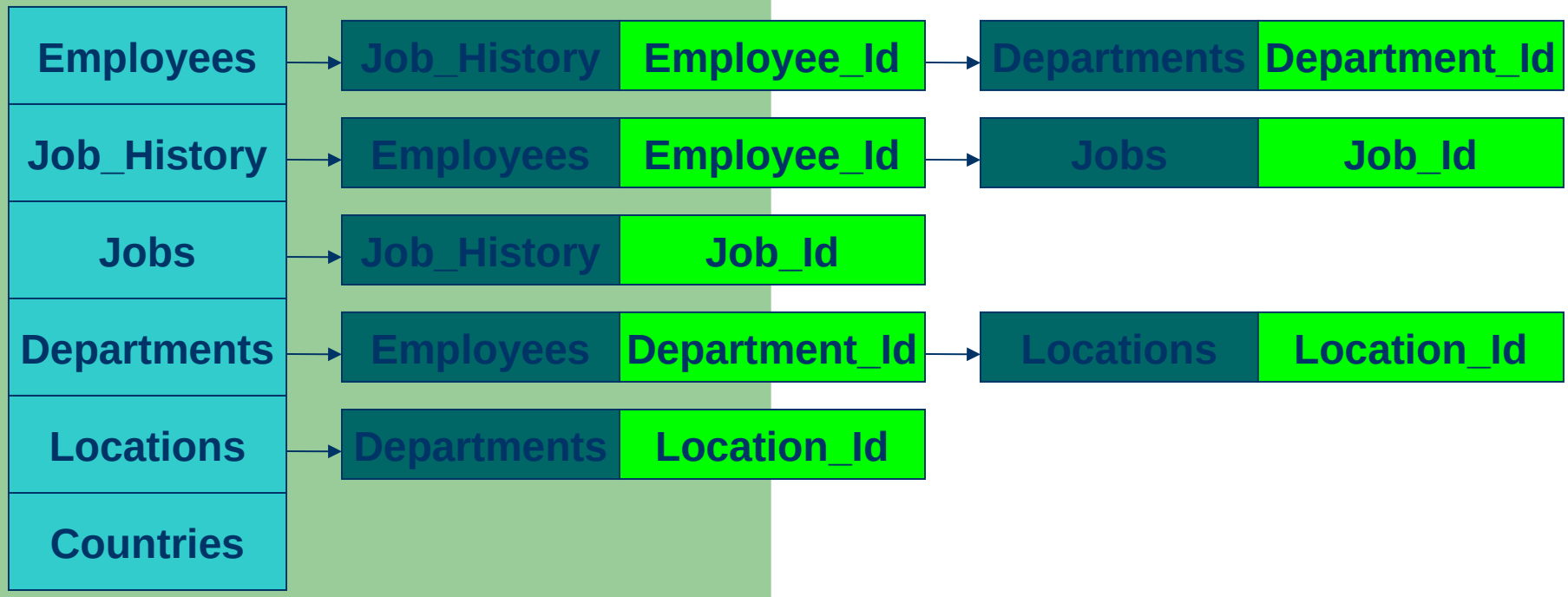

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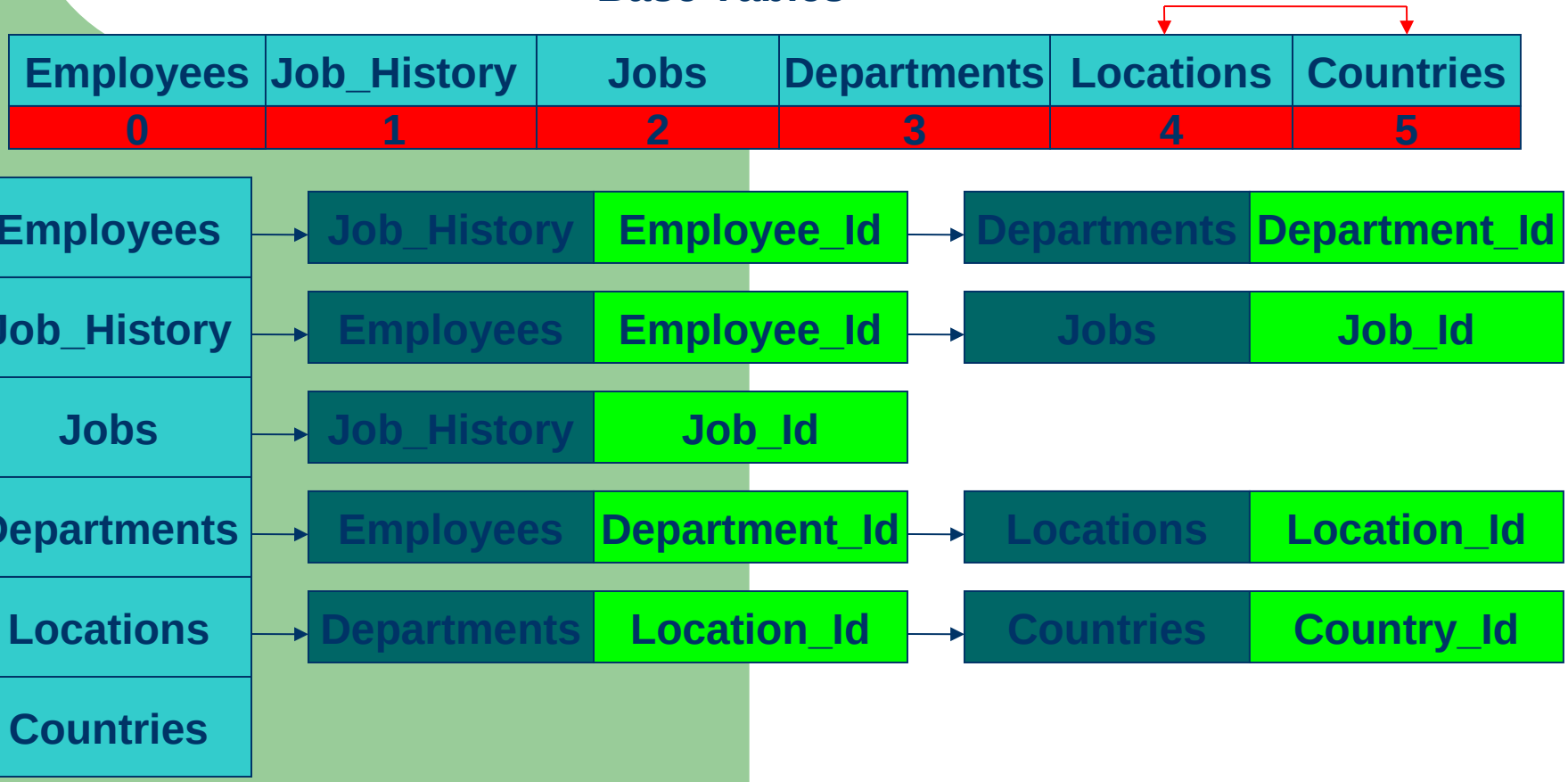

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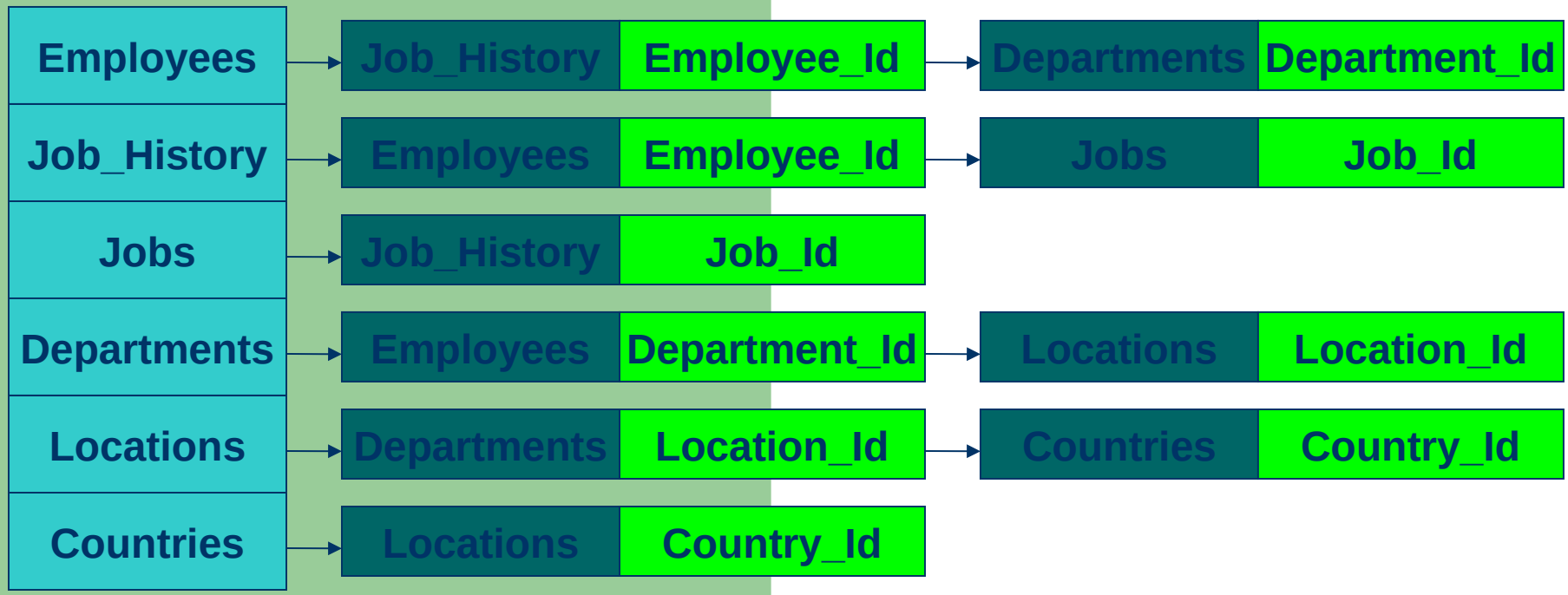
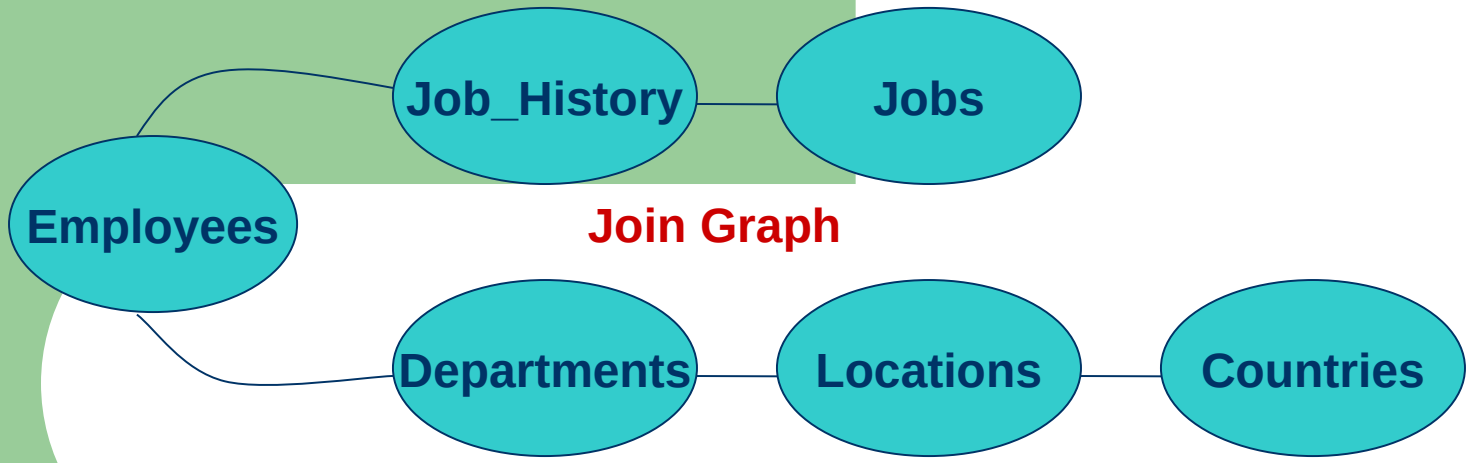
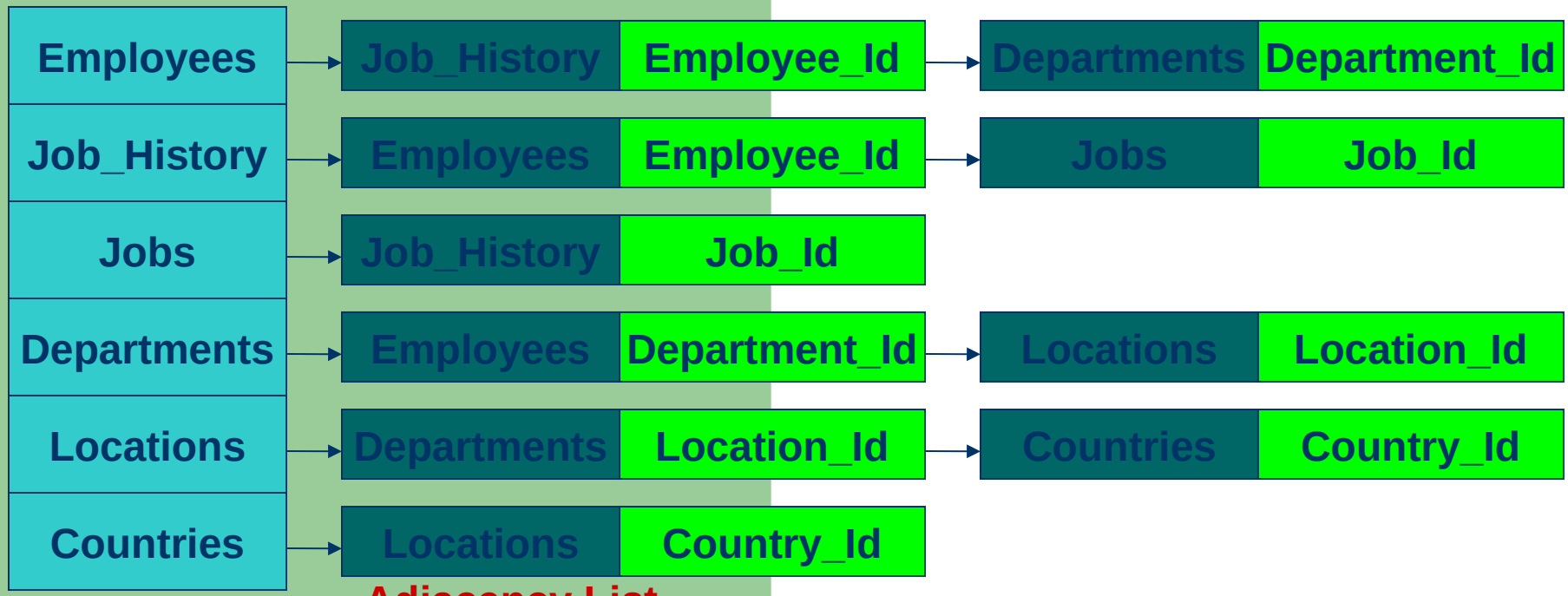




Join Graph

Linked List representation of the Join Graph



Adjacency List

Definitions

Join Path List:

A sequence of tables $T_0 \ldots T_{n-1}$ is in the Join Path List if every T_i of them is at least in direct join with another table in the sequence.

Notation

- When index i is not between brackets like in T_i, it represent a base table T_i.

When index i is between brackets like in $T_{[i]}$, it represent a base table T_i or a virtual table in which index i represent a set of indexes for the base tables forming the virtual table.

Steps to generate function: Key($T_{[j]}$) **getFirstAdjacentListKey($T_{[j]}$, $T_{[k]}$)**

for every Base Table T_l in $T_{[j]}$ do

Take one at a time

for every $T_{Link(l)}$ do

Take one at a time

if $T_{Link(l)}$ in $T_{[k]}$ then

return(key(T_l,$T_{Link(l)}$))

Normally one of the 2 tables $T_{[j]}$ or $T_{[k]}$ is a base table this is why we stop after founding the key.

Key could be a one column key or multicolumn key that satisfy the join condition.

Steps to generate Join Path List for the join sequence $T_0 \ldots T_m$

let $T_0 \ldots T_m$ be the base tables
create 2 dynamic arrays queue and path
insert T_0 into path
insert T_0 into queue
repeat
    $T_{Element}$ = First Table in queue
    for every Link Item in Adjacent Link of $T_{Element}$ from the Join Graph do
        if the Link Item is in the join sequence then
            if path doesn't contain the Link Item then
                insert Link Item into path
                insert Link Item into queue
    remove $T_{Element}$ from queue
until queue is empty

Steps to generate Join Path List for the join sequence $T_0 \ldots T_m$ (continue)

insert all the names of base tables from path as vertexes in the JoinPathList

create a local buffer buf

insert into buf the first entry from path

for all the remainder entries in path do

- **take one T_i at a time**
- **PathJoinAdjacentList(T_i) = $T_{[buf]}$**
- **Key(T_i) = getFirstAdjacentListKey(T_i,$T_{[buf]}$)**
- **PathJoinAdjacentList($T_{[buf]}$) = T_i**
- **Key($T_{[buf]}$) = getFirstAdjacentListKey ($T_{[buf]}$,T_i)**
- **$T_{[buf]}$ + = T_i**
- **Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$**

Steps to generate Join Path List for the join sequence $T_0 \ldots T_m$ (continue)

create a structure buf with 2 fields: Table and Key

for all the tables in JoinPathList going downward do

- **take one $T_{[i]}$ at a time**
- **for all Base Tables in$T_{[i]}$ do**
  - **take one T_k at a time**
  - **for every buf.Table = T_k do**
    - **if (buf.key != Key($T_{[i]}$)) and (buf.Key not in InheritedKey($T_{[i]}$)) then**
      InheritedKey($T_{[i]}$) += buf.key
- **if T_l is the table from which comes Key($T_{[i]}$) then**
  - **buf.Table = T_l**
  - **buf.key = Key($T_{[i]}$)**

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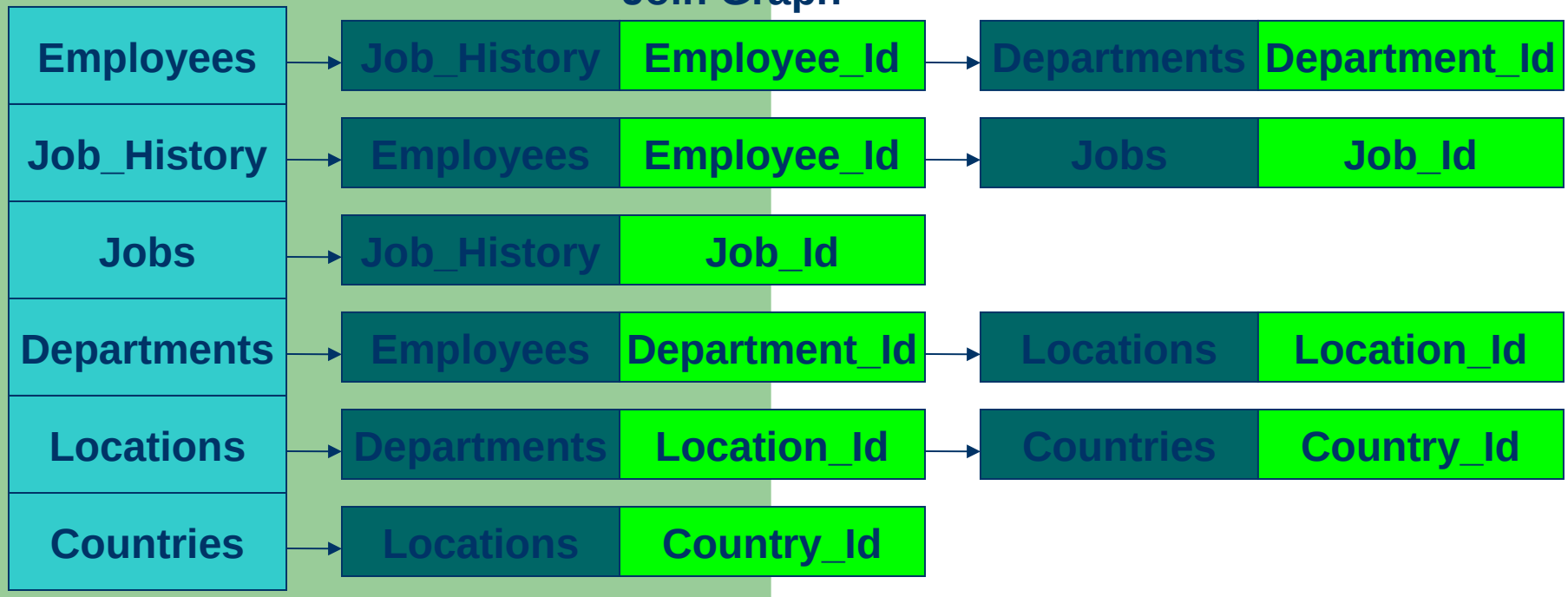
Join Graph



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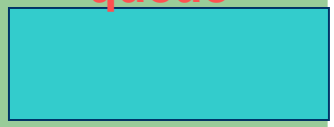
queue



path

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    remove $T_{Element}$ from queue

until queue is empty

queue

path

Employees

generateJoinPathList (in Join Base Tables, JoinGraph; out JoinPathList)

let $T_0 \ldots T_m$ be the base tables

create 2 dynamic arrays queue and path

insert T_0 into path

insert T_0 into queue

repeat

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Employees

path

Employees

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Employees

path

Employees

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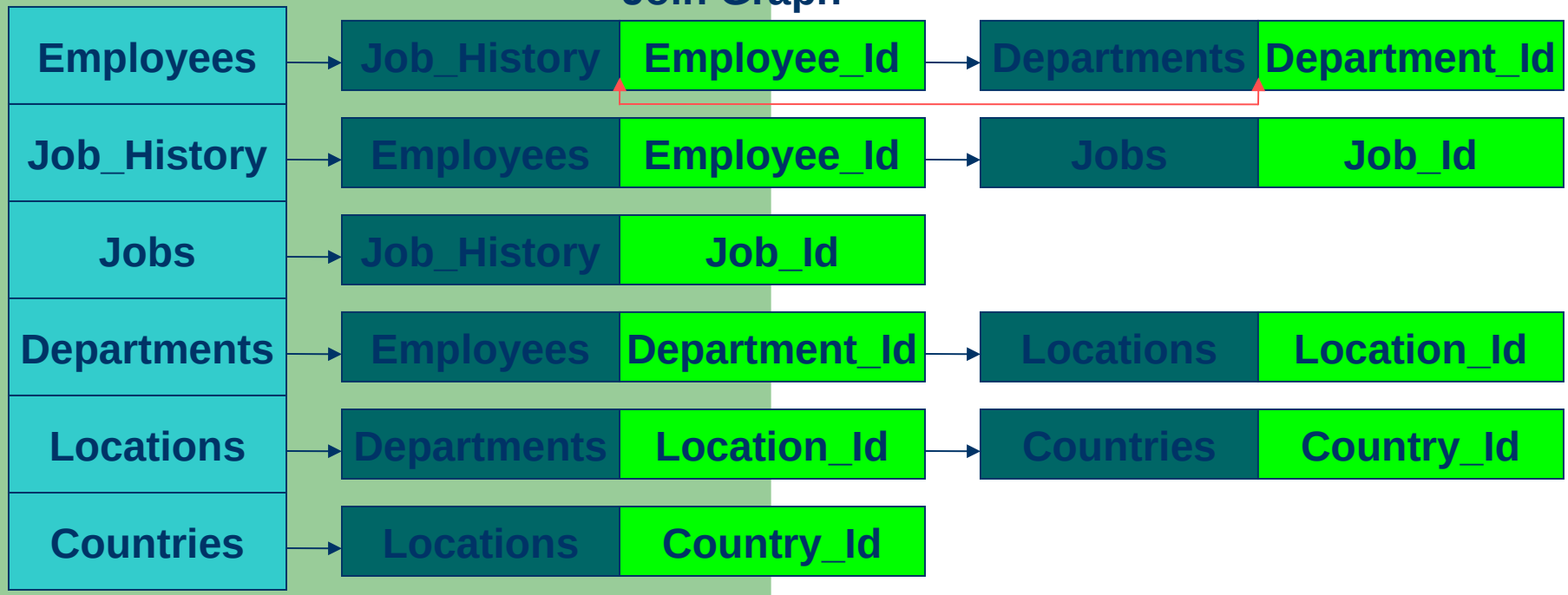
Join Graph



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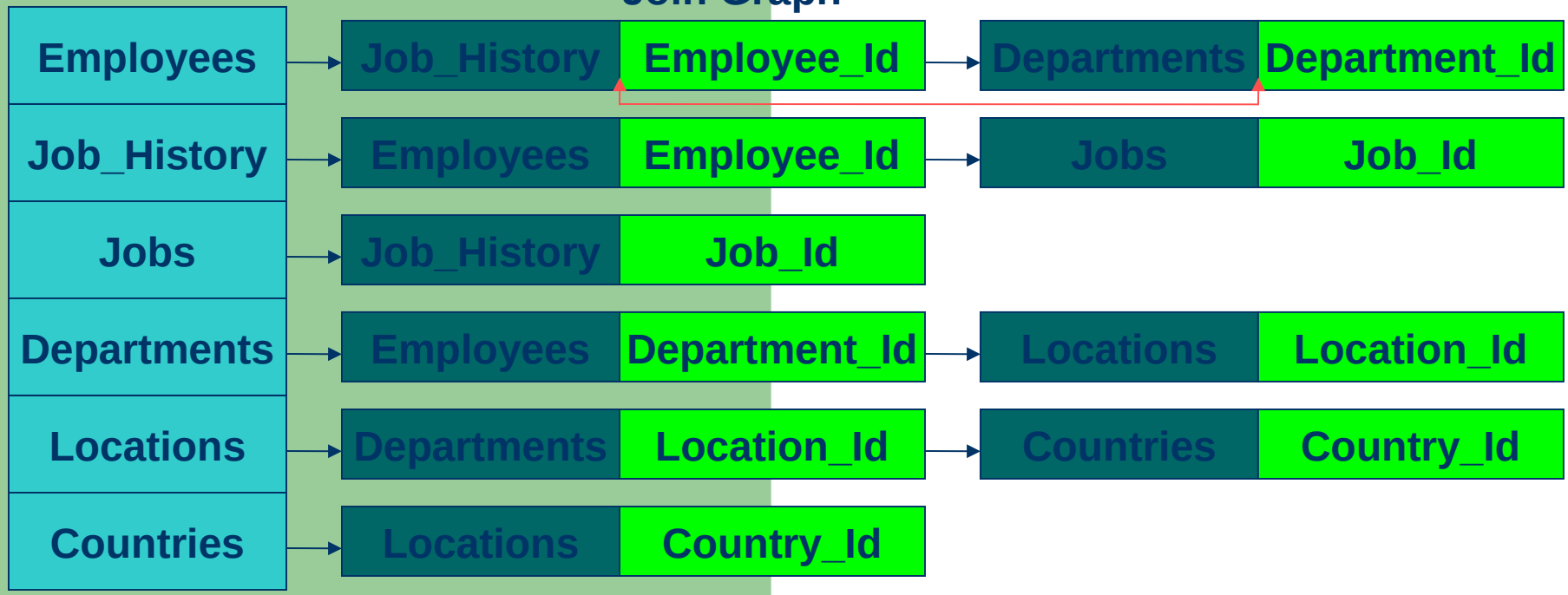
Join Base Tables

Join Graph



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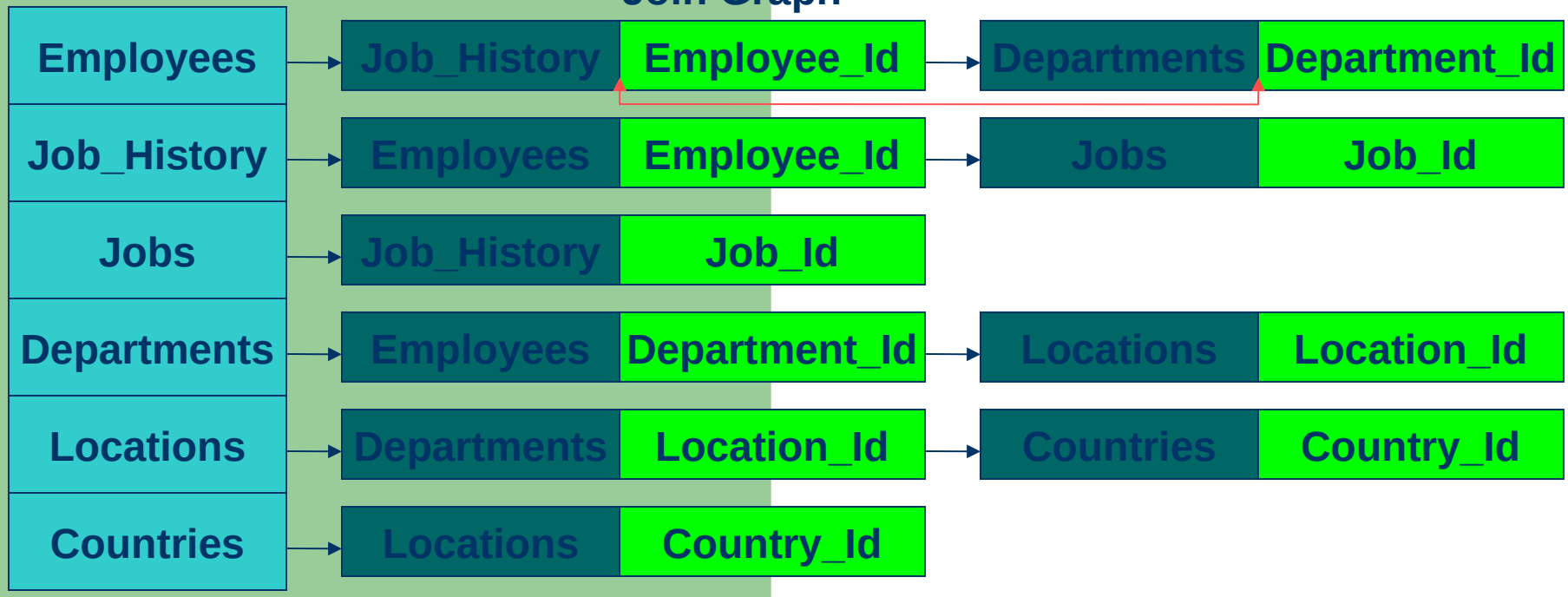
path

Employees

Join Base Tables

Employees	Job_History	Jobs	Departments	Locations	Countries

Join Graph



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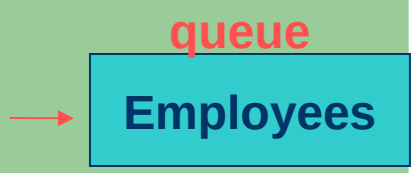

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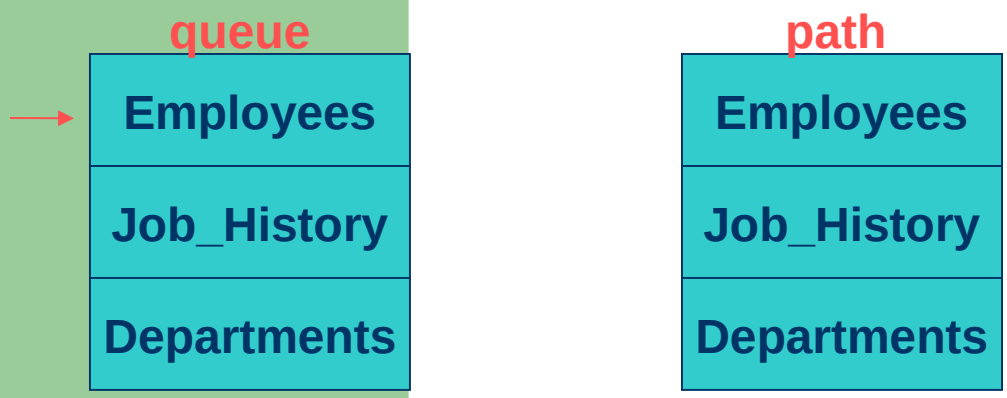

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queue

Job_History
Departments

path

Employees
Job_History
Departments

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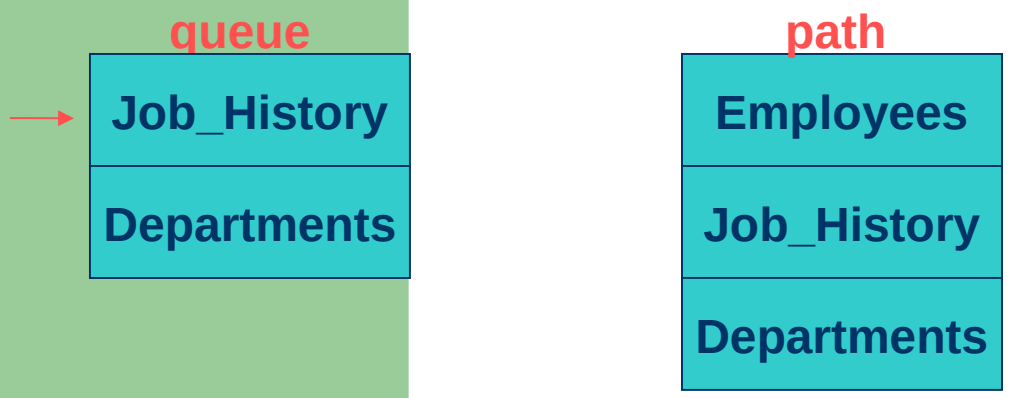

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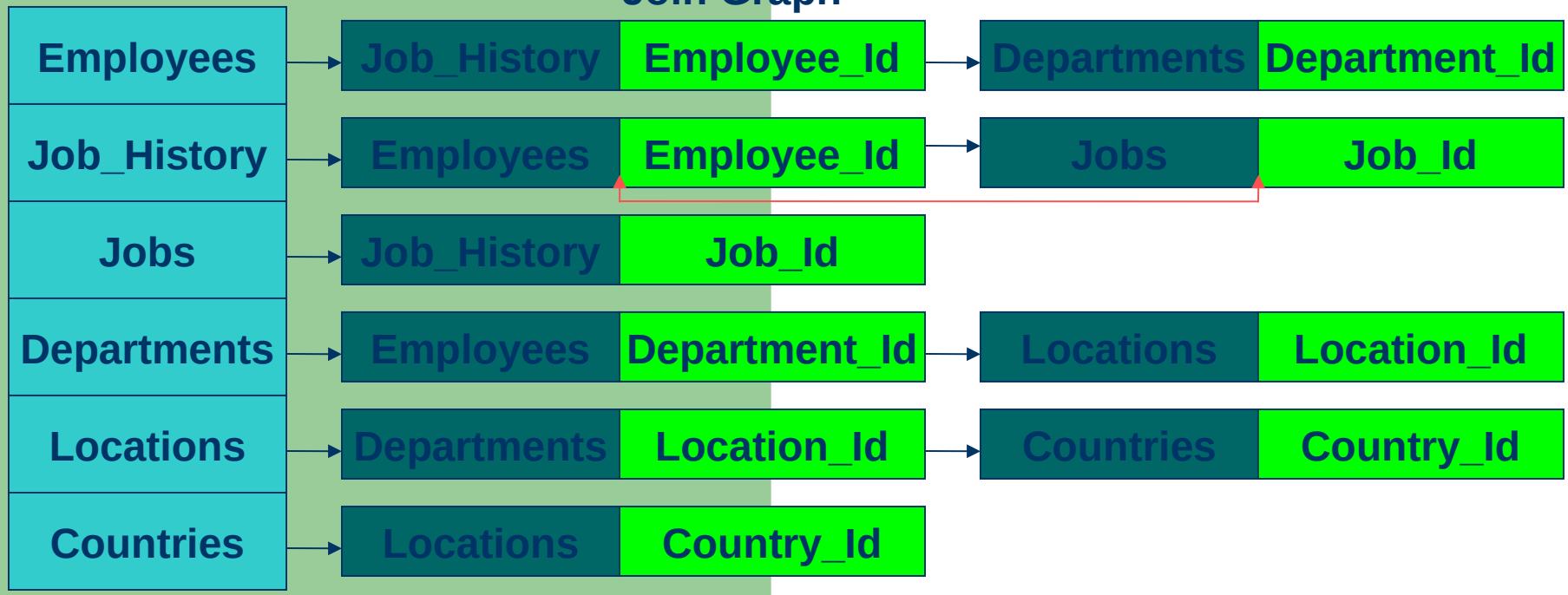
Join Graph



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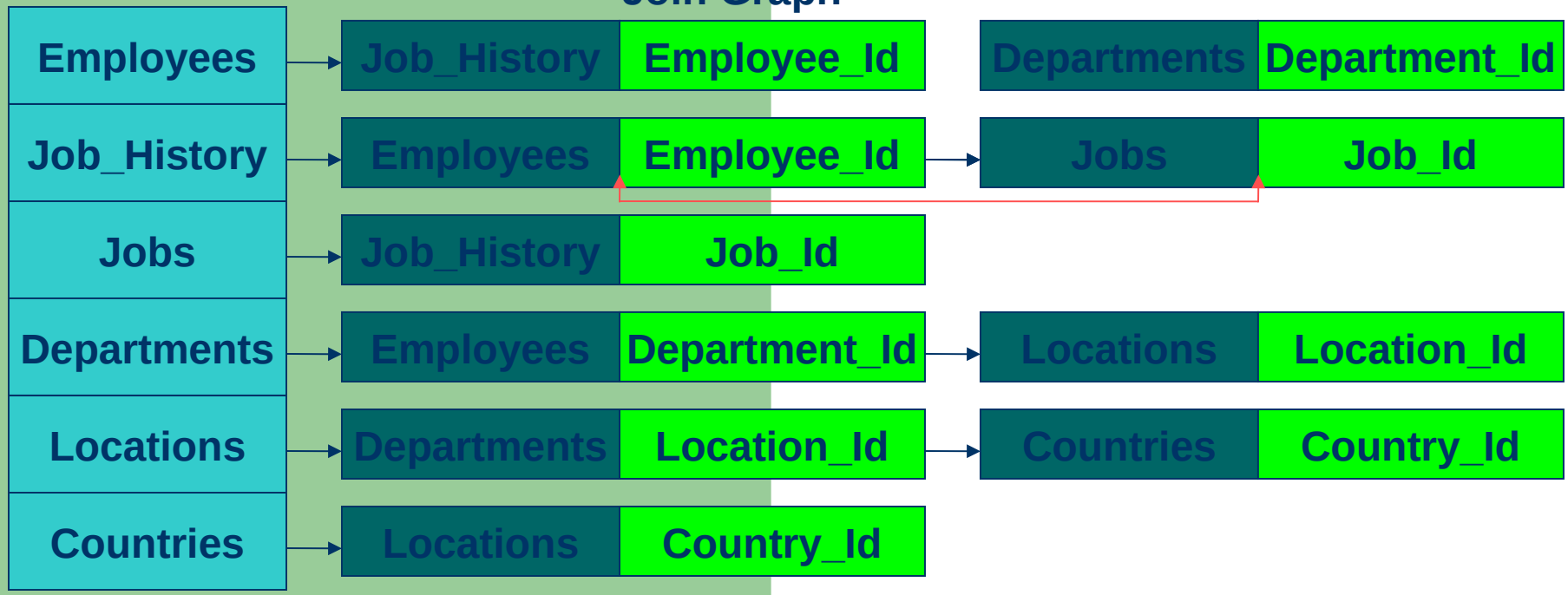
Join Base Tables

Join Graph



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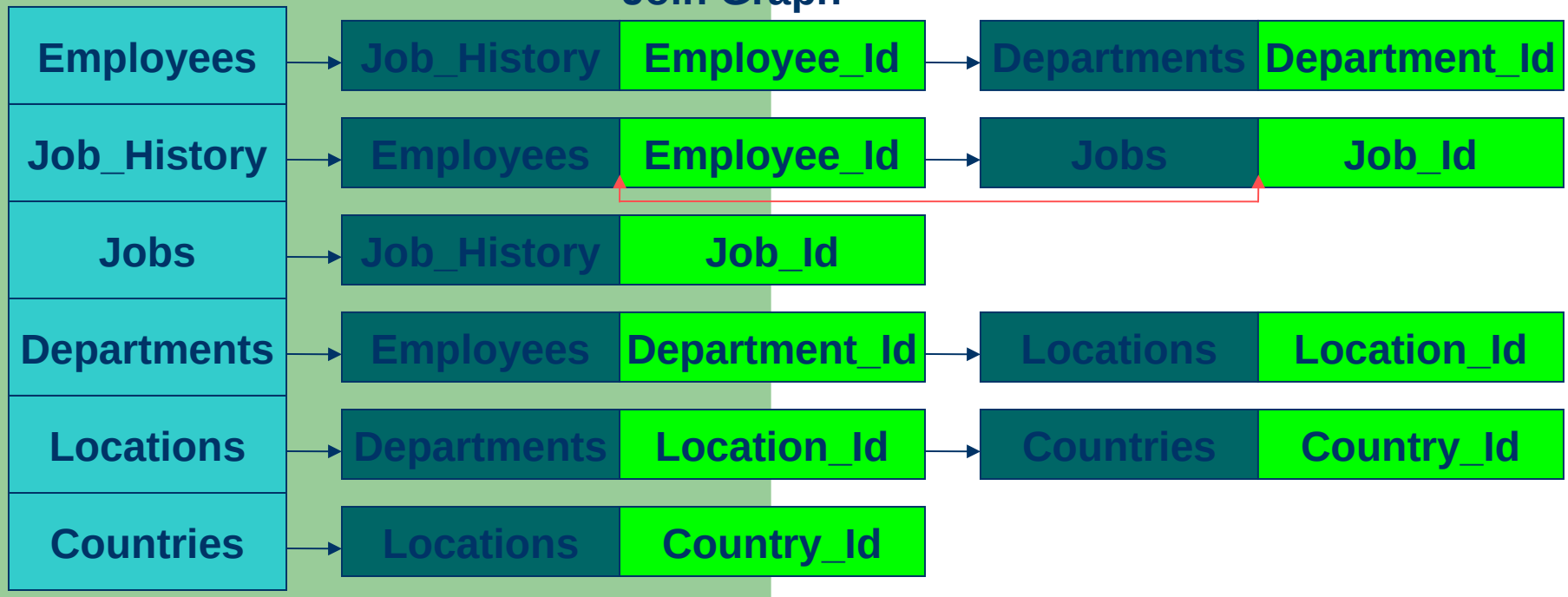
path

- Employees
- Job_History
- Departments

Join Base Tables

Employees | Job_History | Jobs | Departments | Locations | Countries

Join Graph



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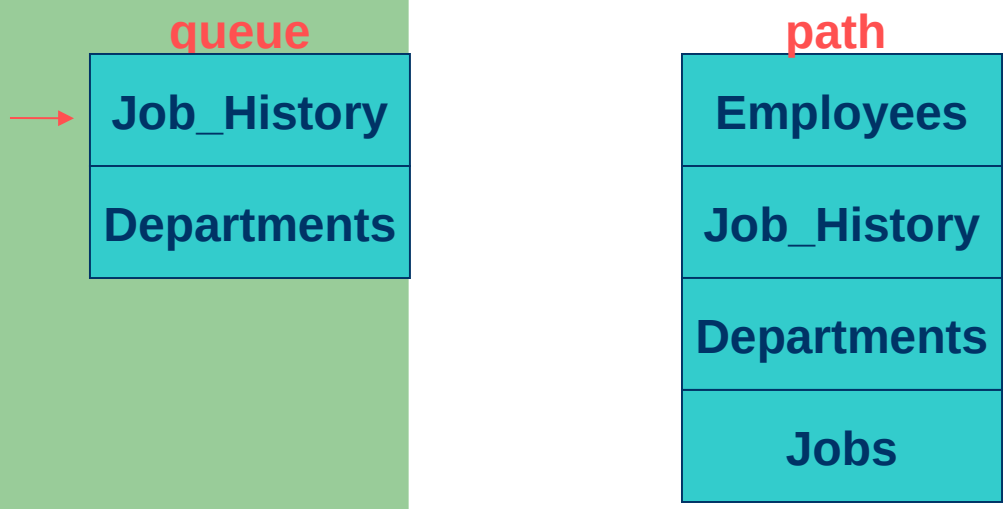

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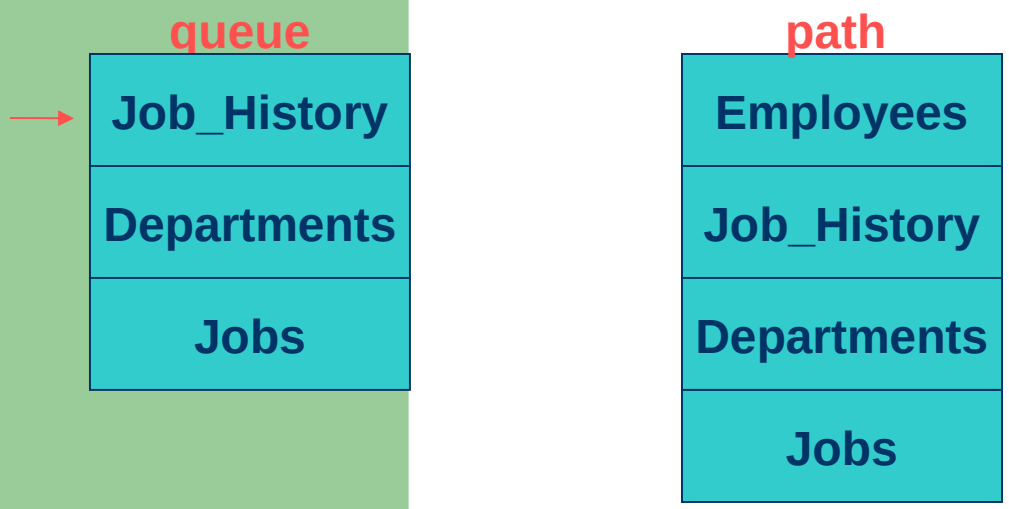

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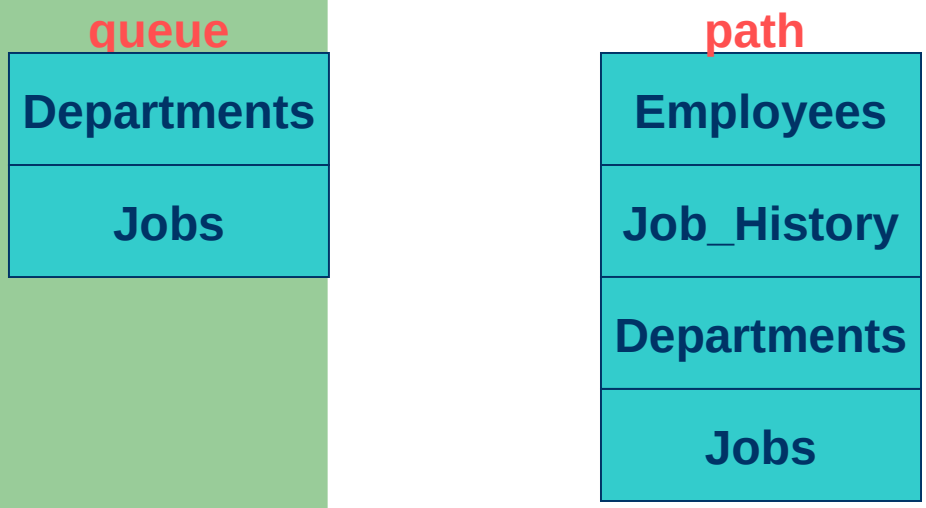

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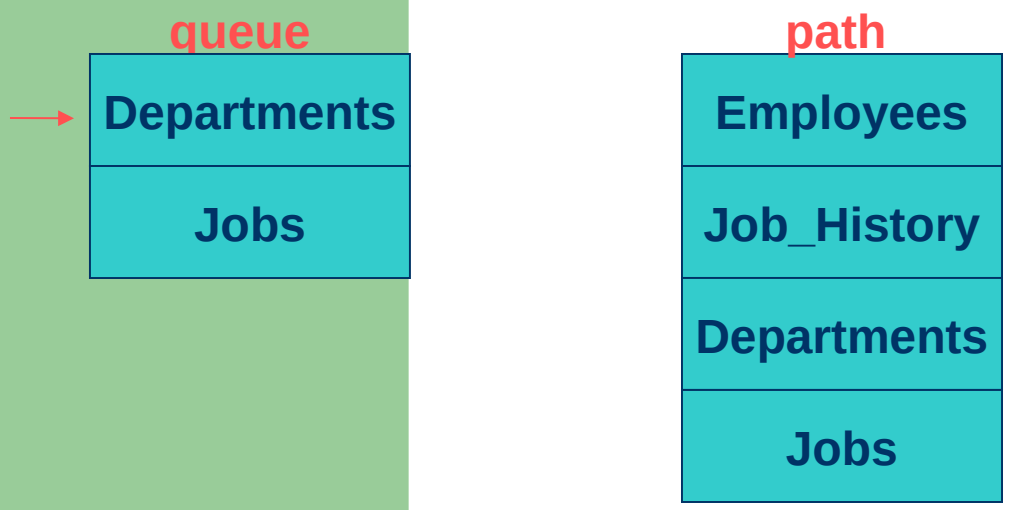

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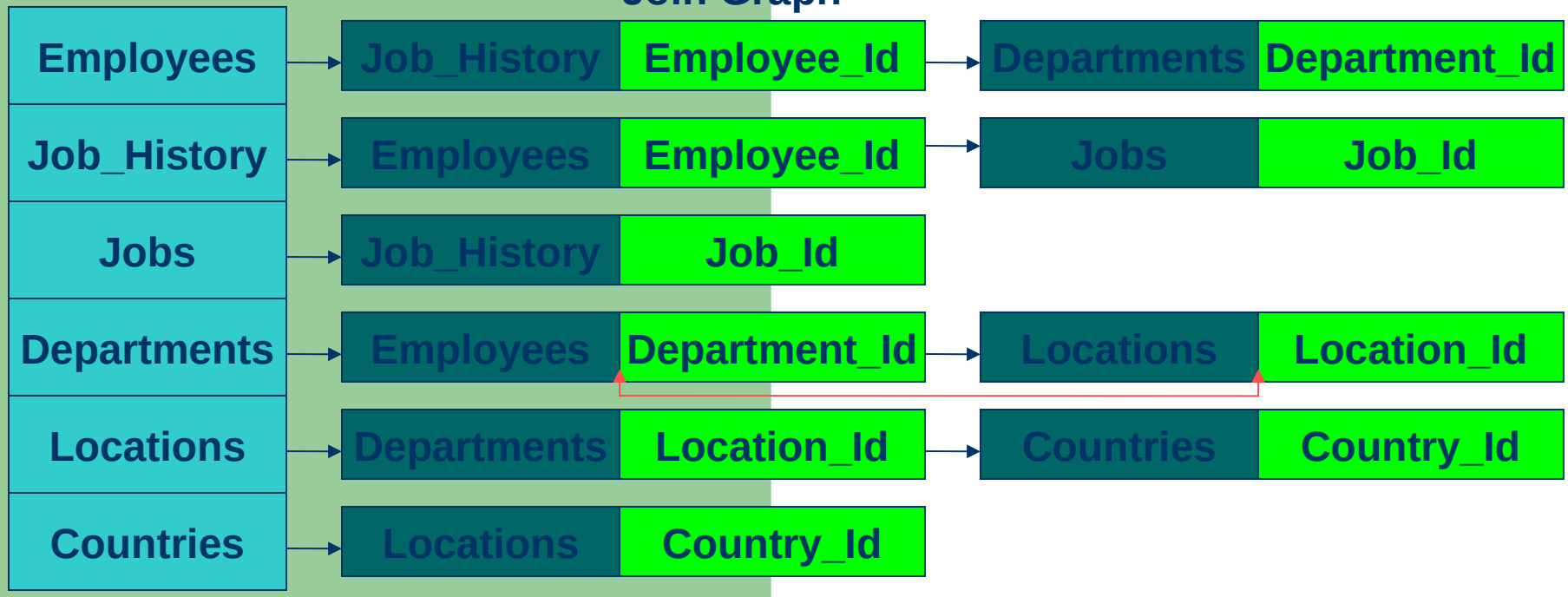
Join Graph



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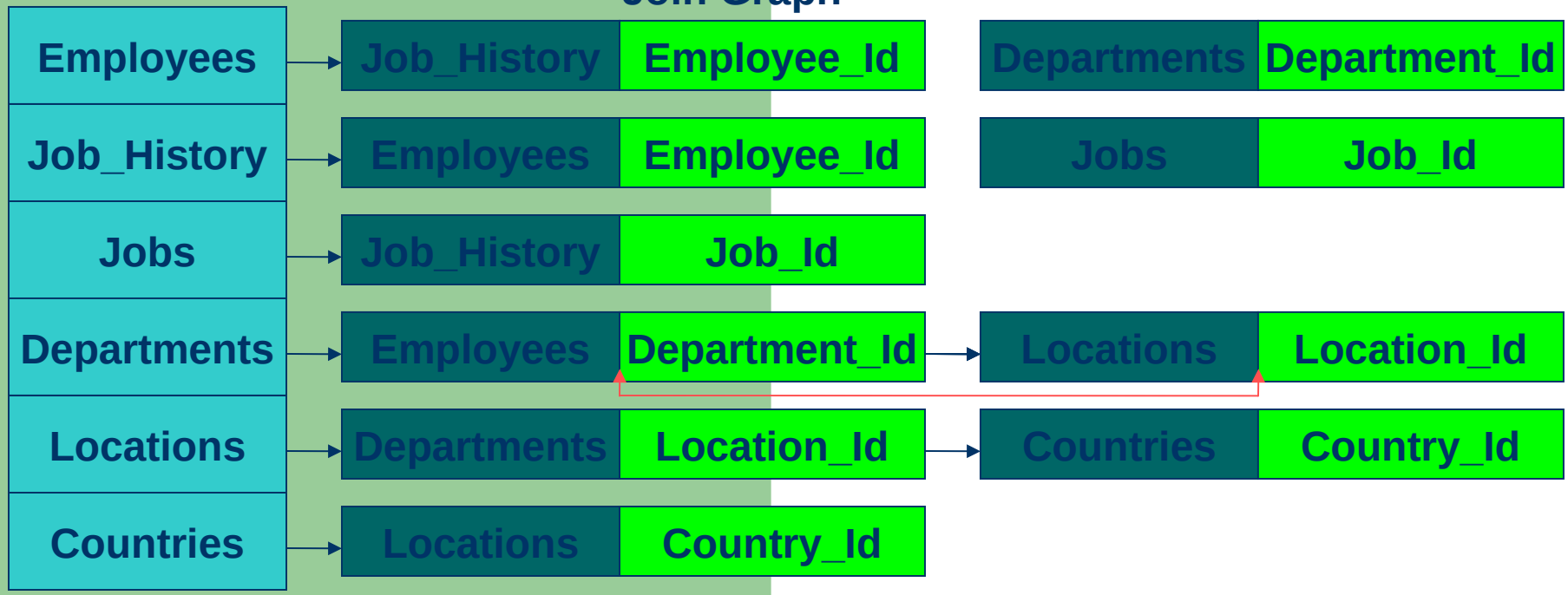
Join Base Tables

Join Graph



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path

Employees	Jobs
Job_History	
Departments	

Join Base Tables

Employees	Job_History	Jobs	Departments	Locations	Countries

Join Graph

Employees	Job_History	Employee_Id	Departments	Department_Id
Job_History	Employees	Employee_Id	Jobs	Job_Id
Jobs	Job_History	Job_Id		
Departments	Employees	Department_Id	Locations	Location_Id
Locations	Departments	Location_Id	Countries	Country_Id
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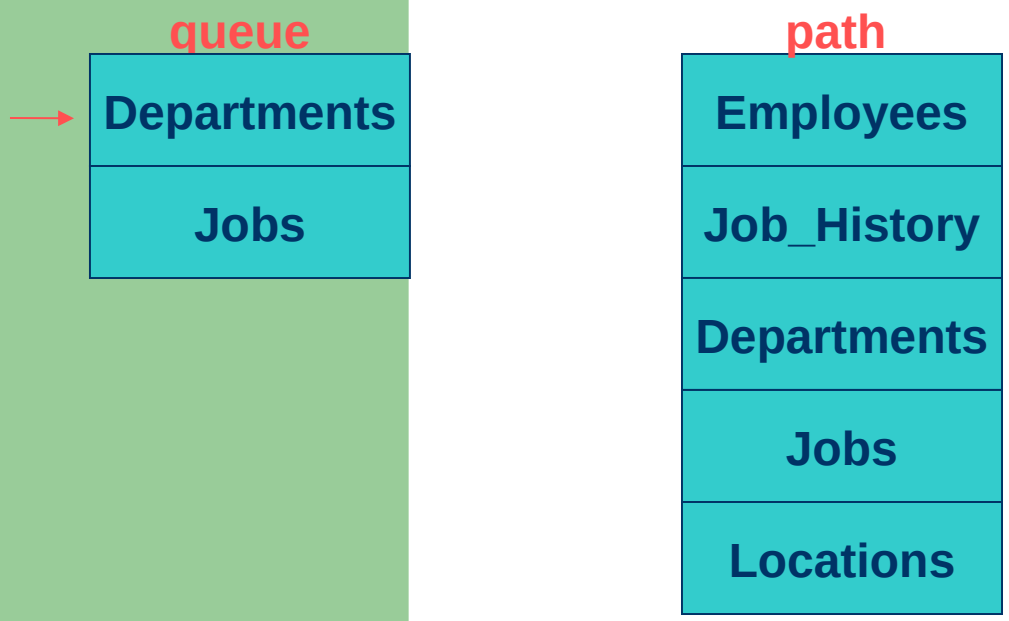

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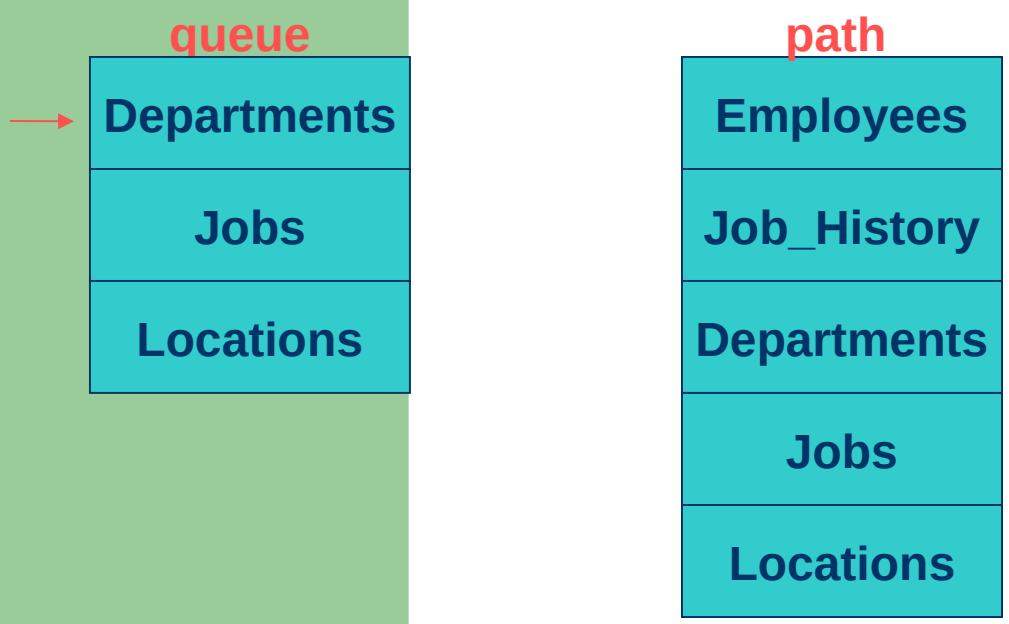

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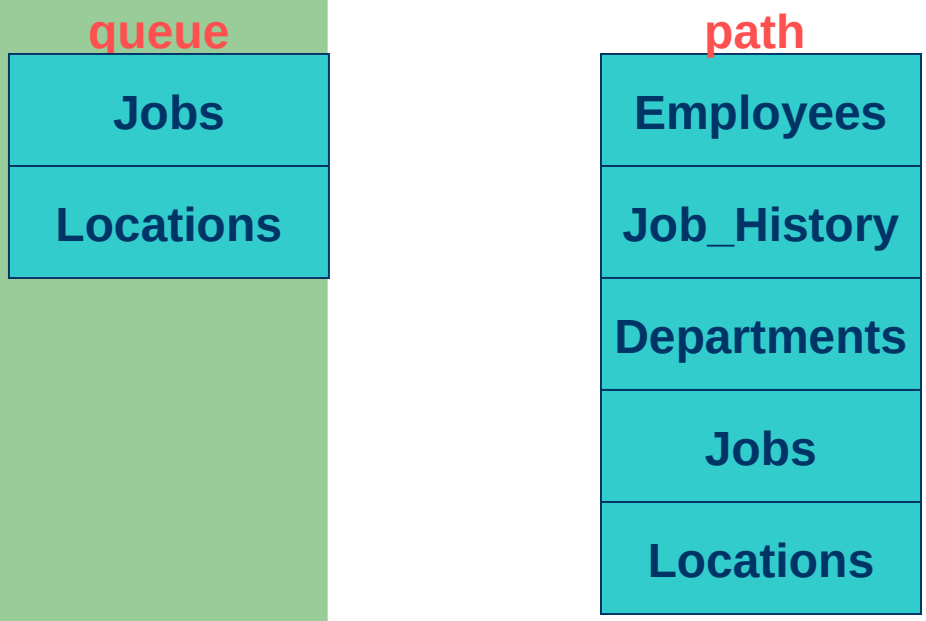

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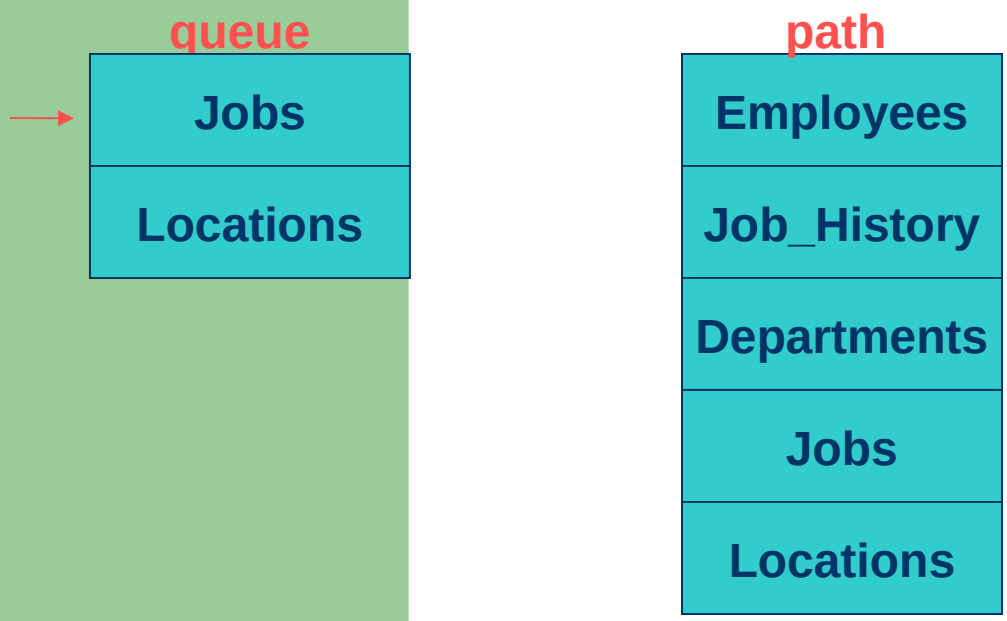

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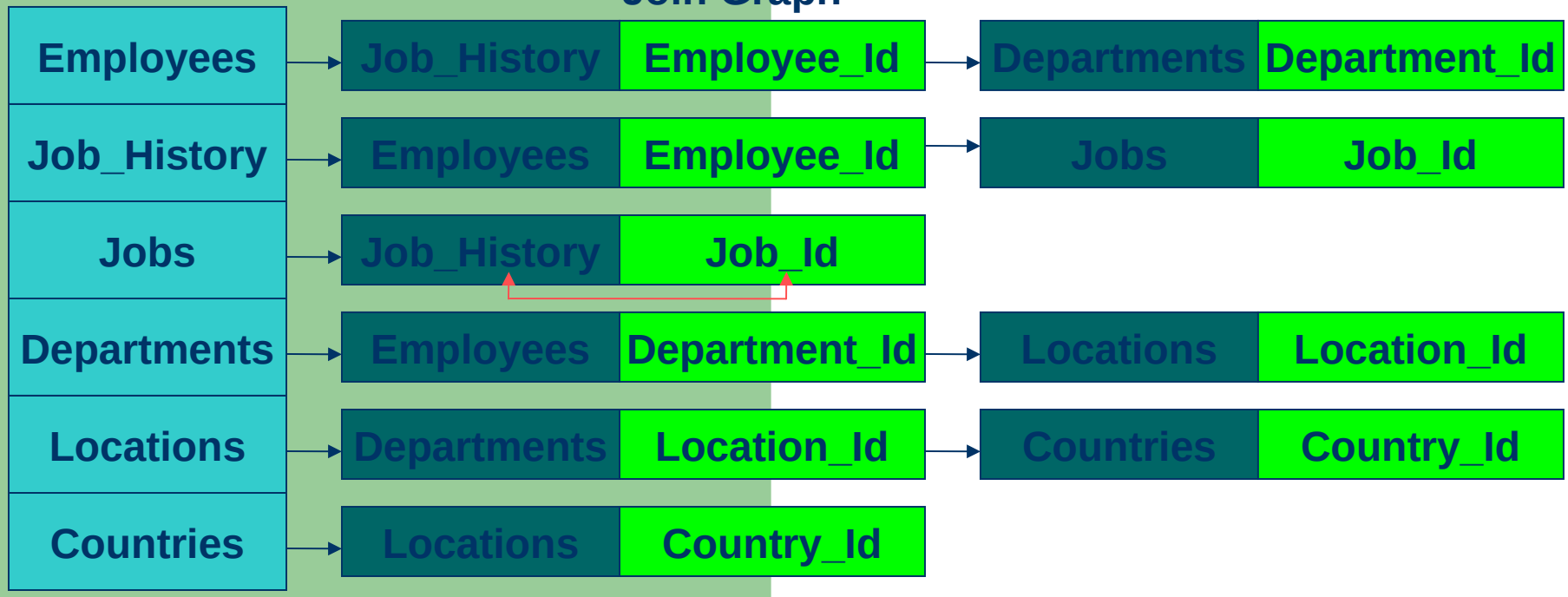

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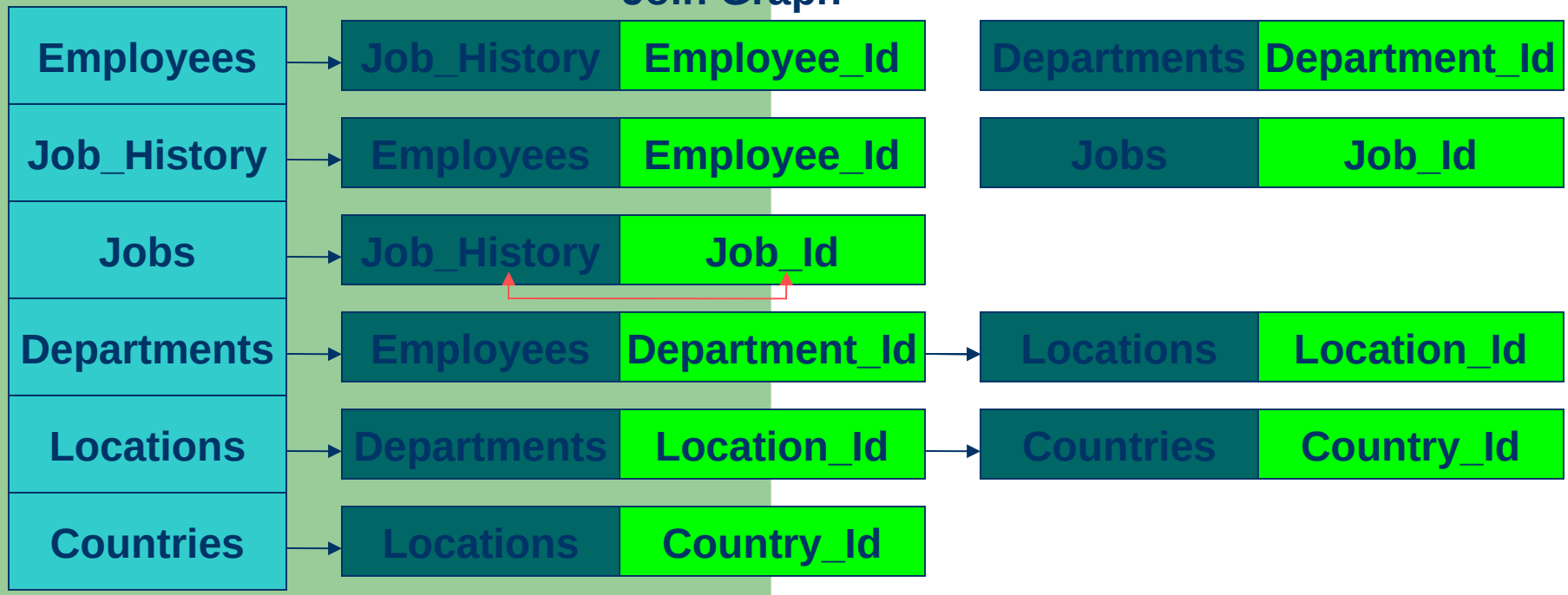
Join Base Tables

Join Graph



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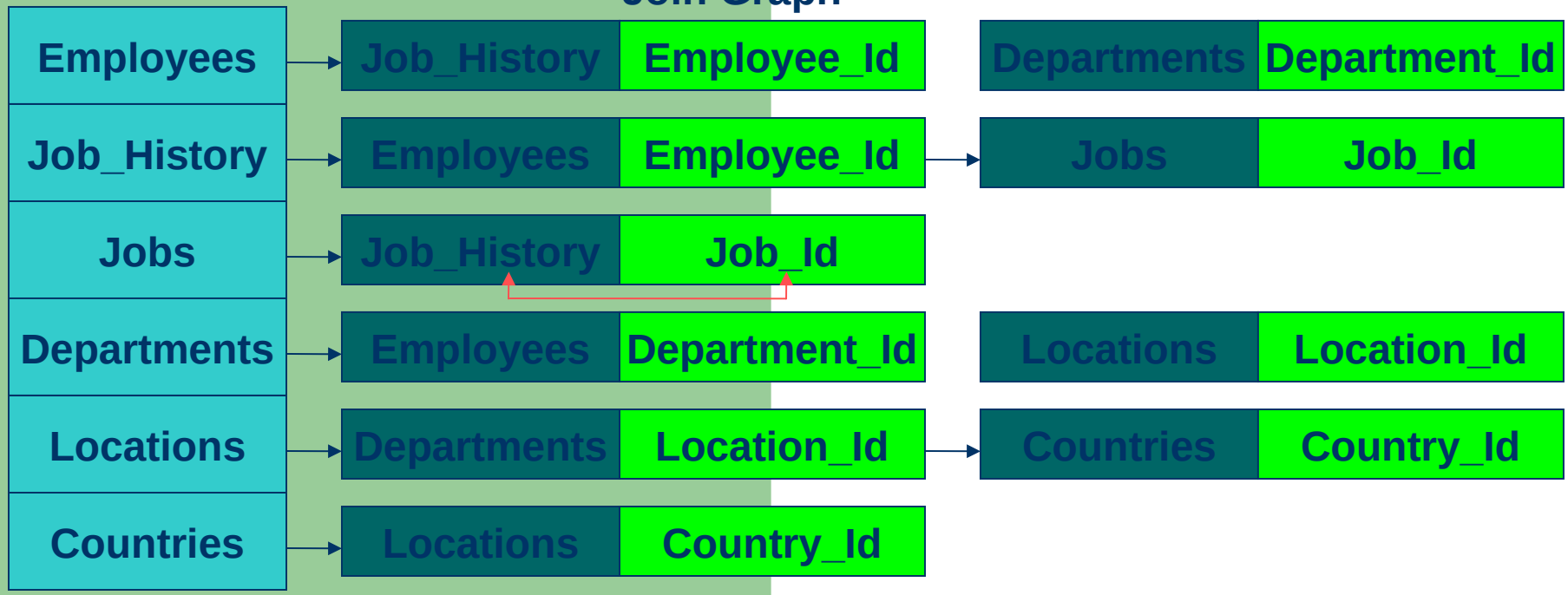
path

Employees	Jobs
Job_History	Locations
Departments	

Join Base Tables

Employees	Job_History	Jobs	Departments	Locations	Countries

Join Graph



generateJoinPathList (in Join Base Tables, JoinGraph; out JoinPathList)

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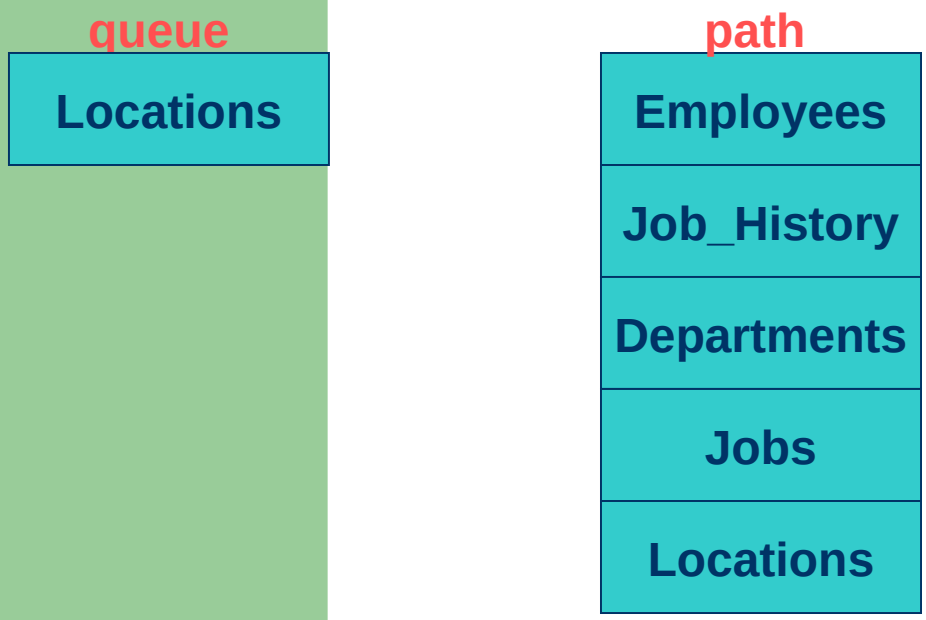

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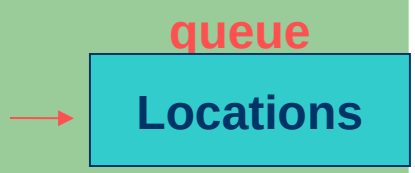

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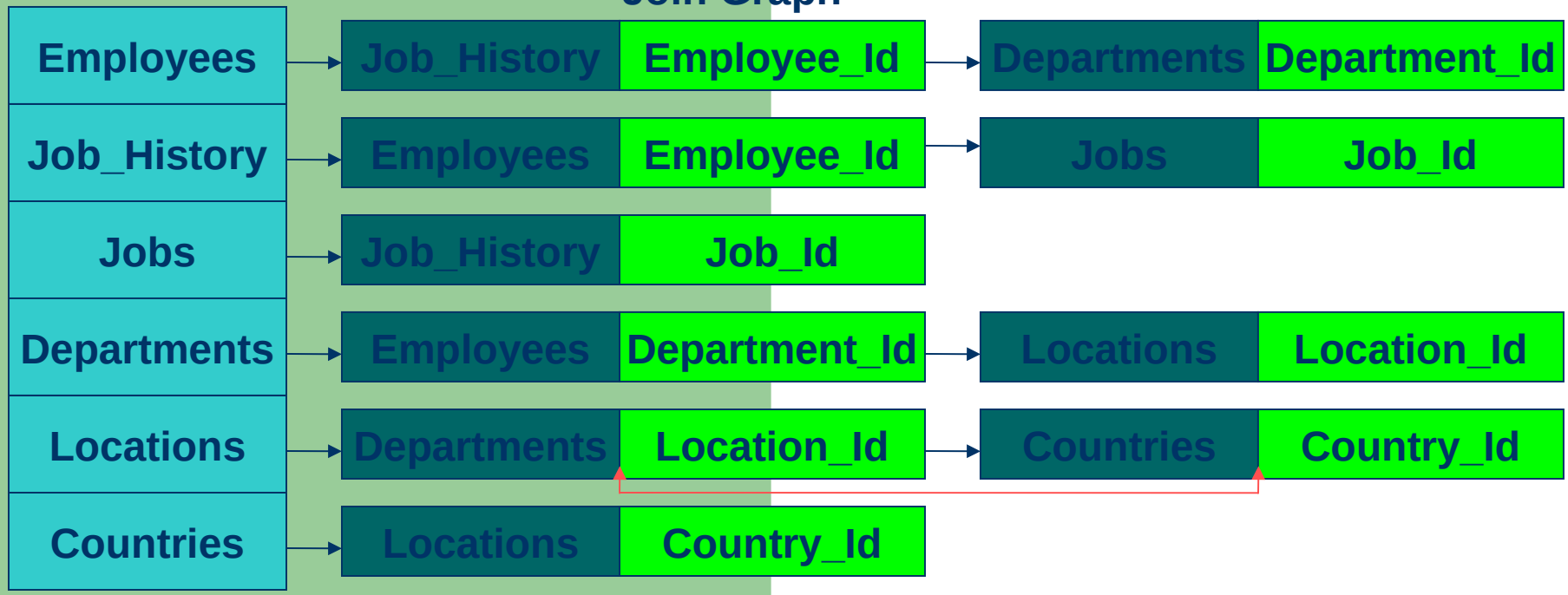
Join Graph



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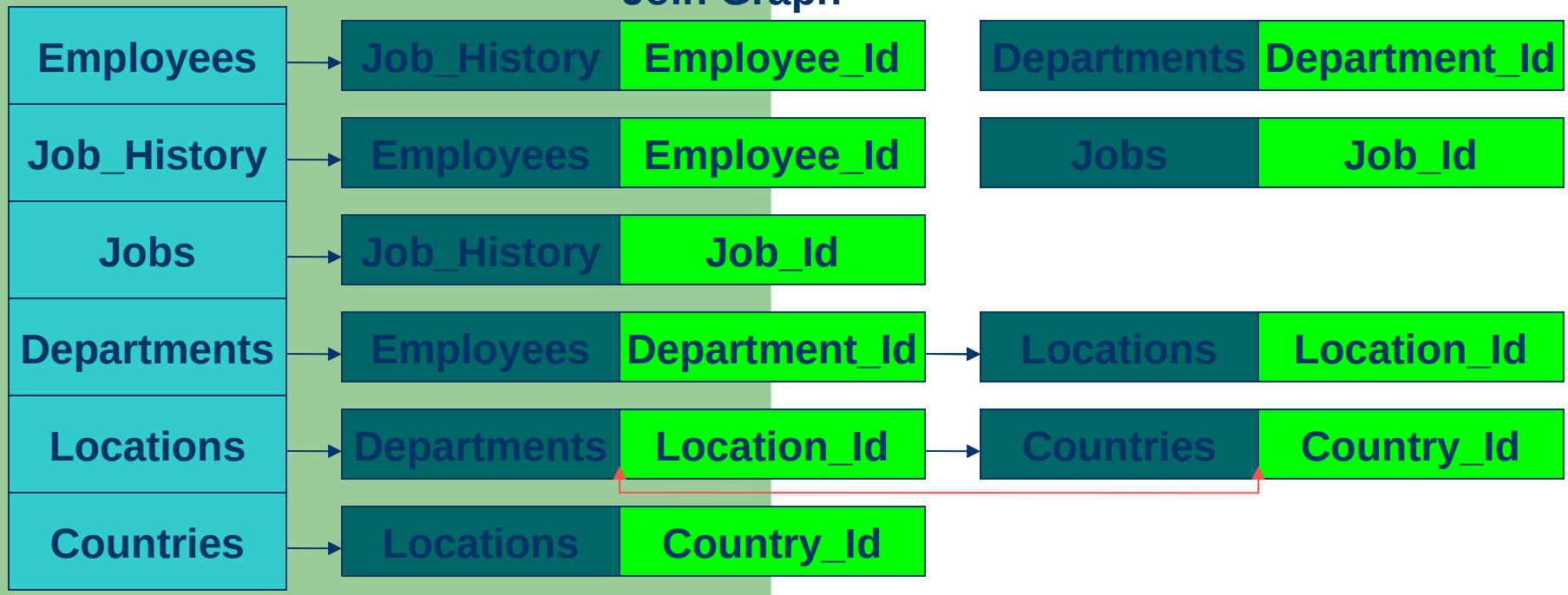
Join Base Tables

Join Graph



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until queue is empty

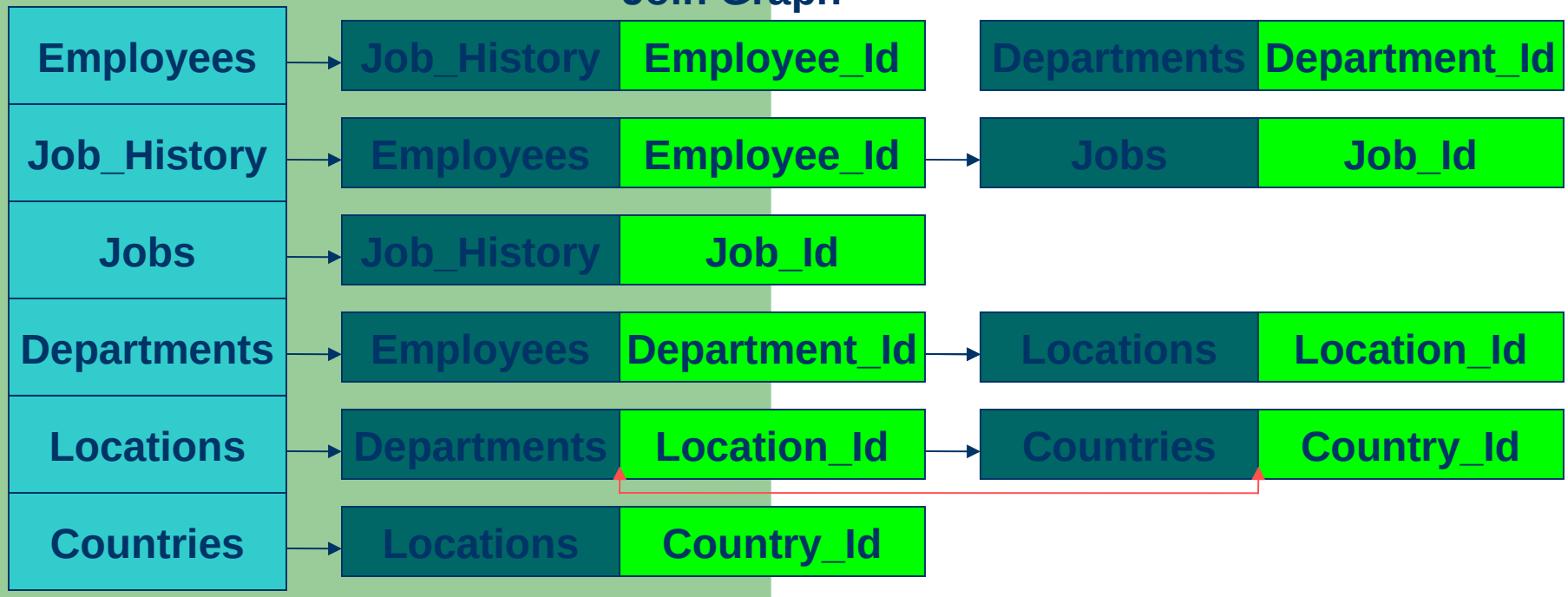
path

Employees	Jobs
Job_History	Locations
Departments	

Join Base Tables

Employees	Job_History	Jobs	Departments	Locations	Countries

Join Graph



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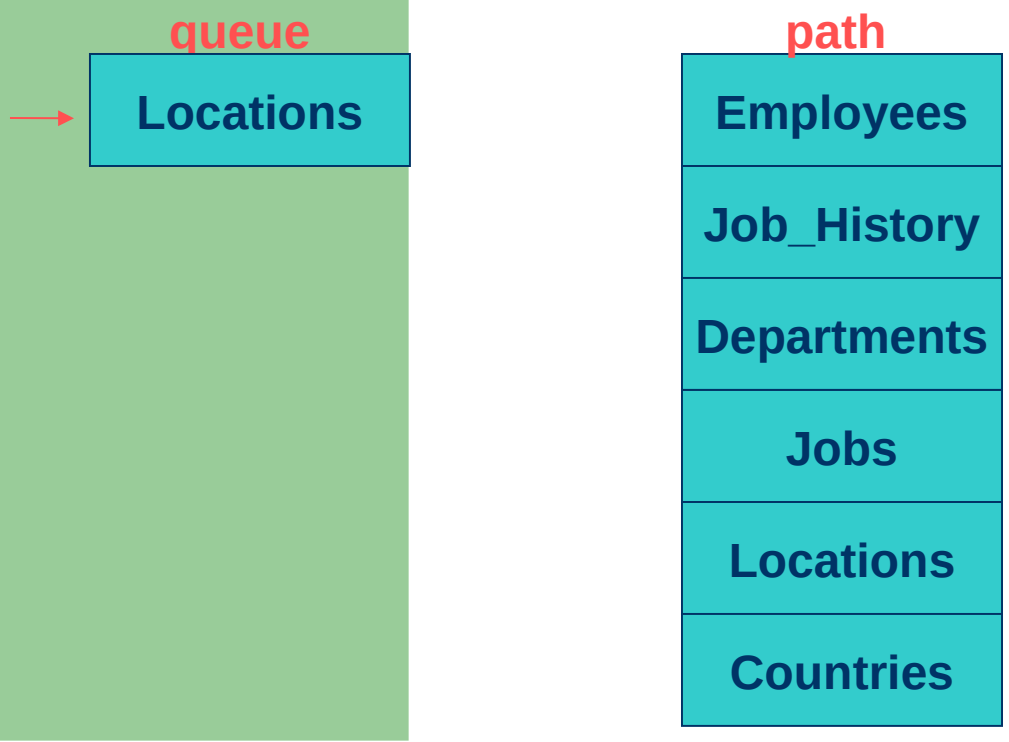

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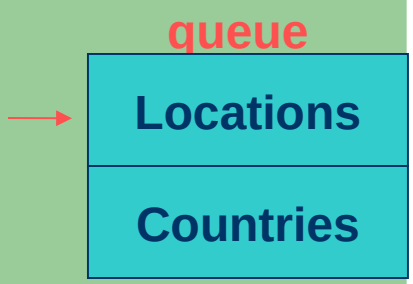

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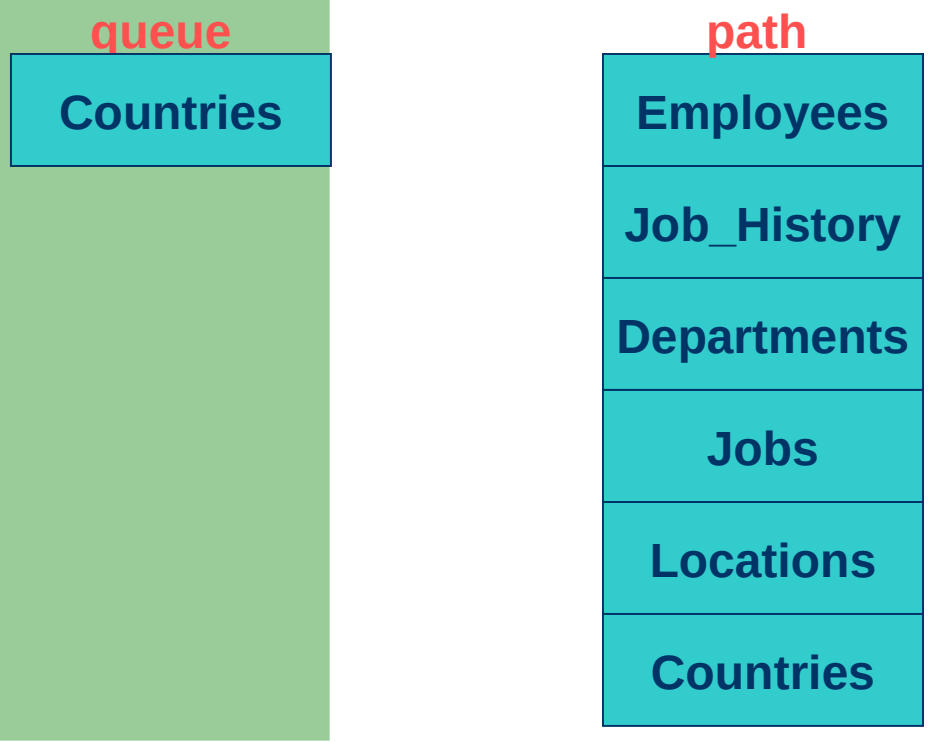

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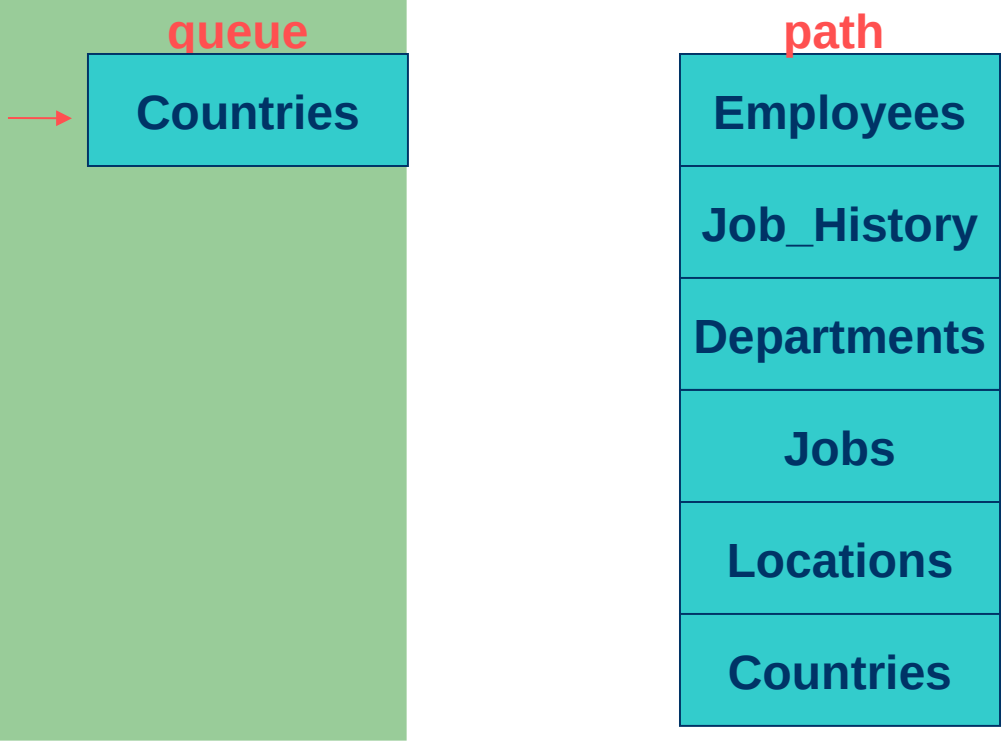

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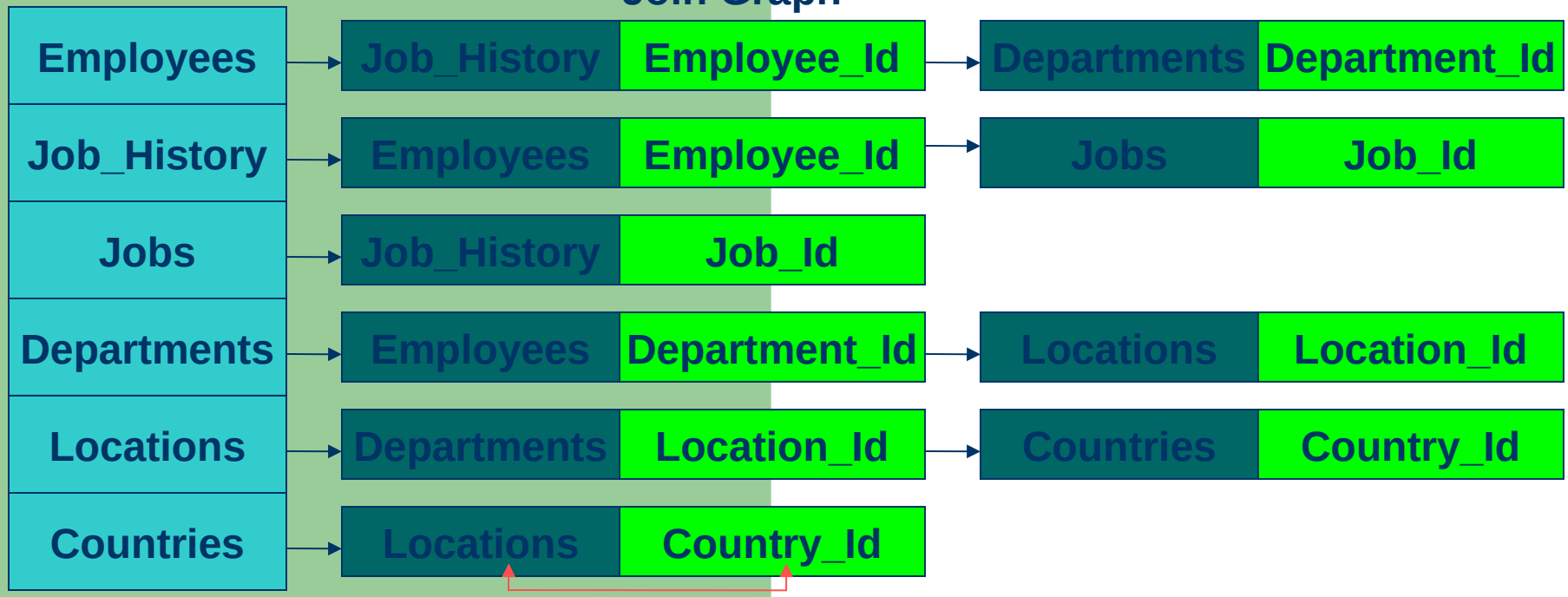
Join Graph



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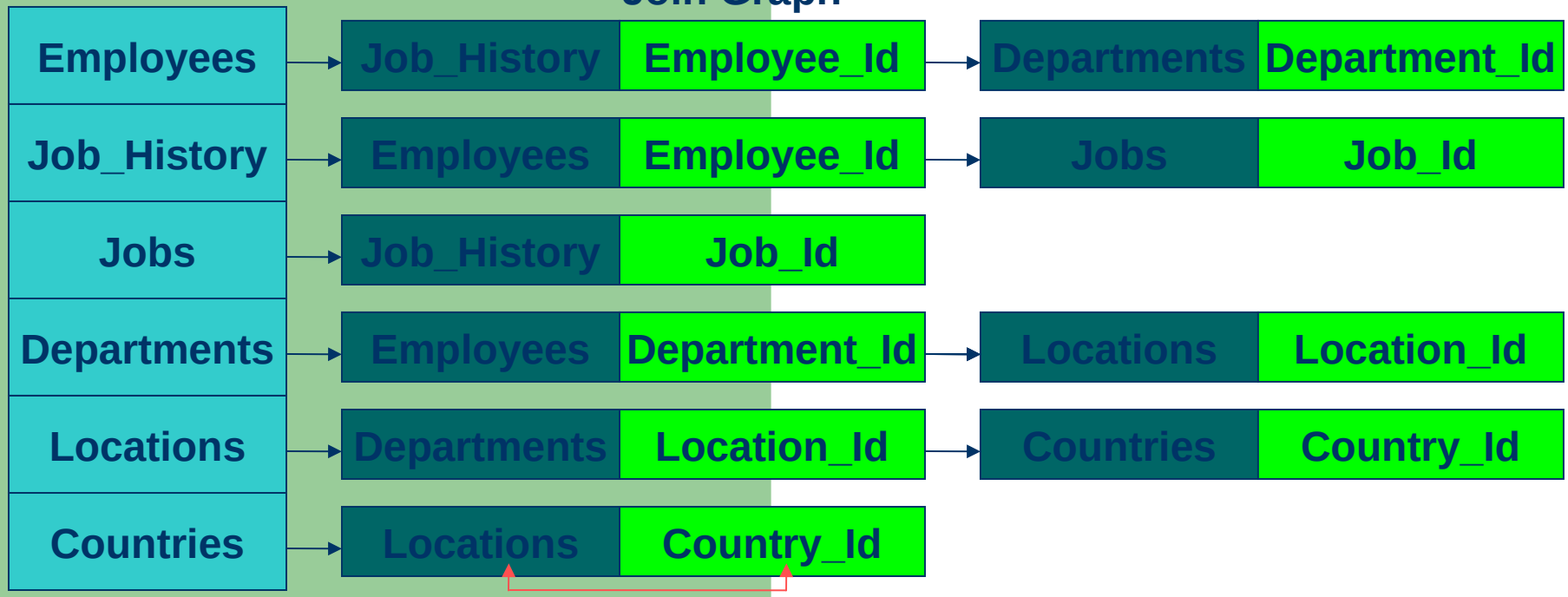
Join Base Tables

Join Graph



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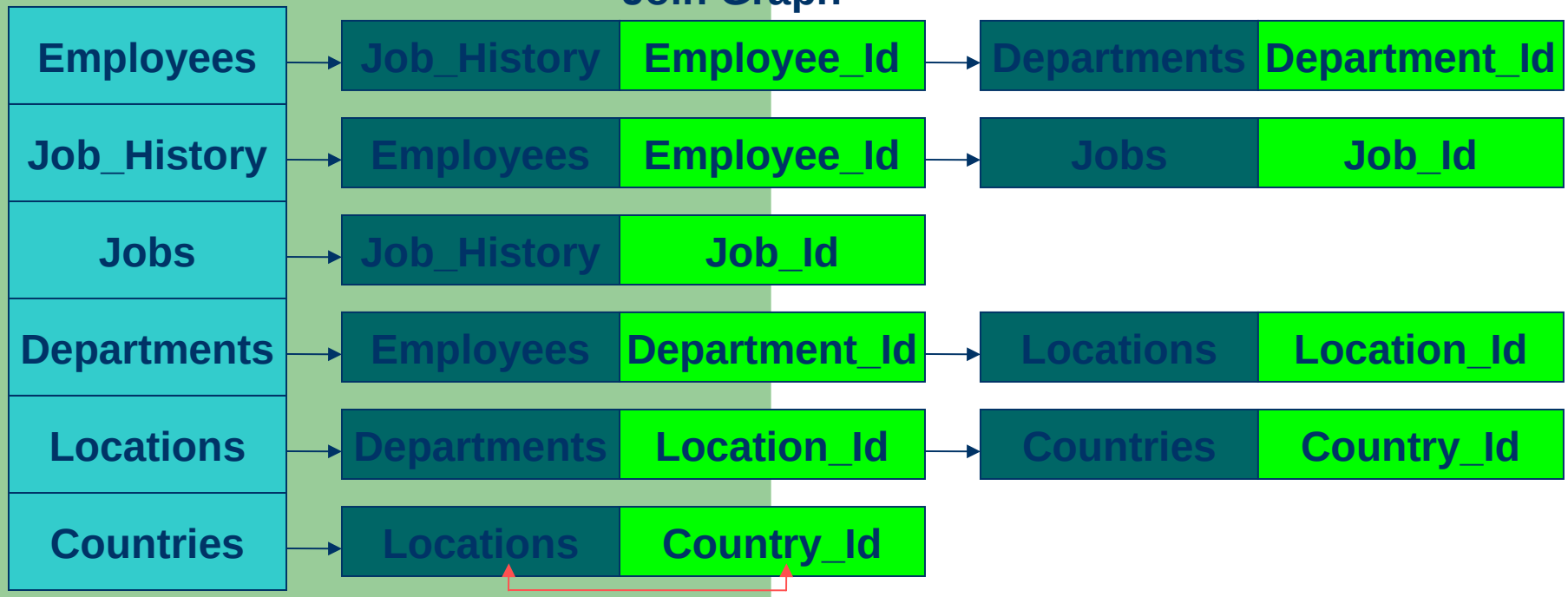
path

Employees	Jobs
Job_History	Locations
Departments	Countries

Join Base Tables

Employees	Job_History	Jobs	Departments	Locations	Countries

Join Graph



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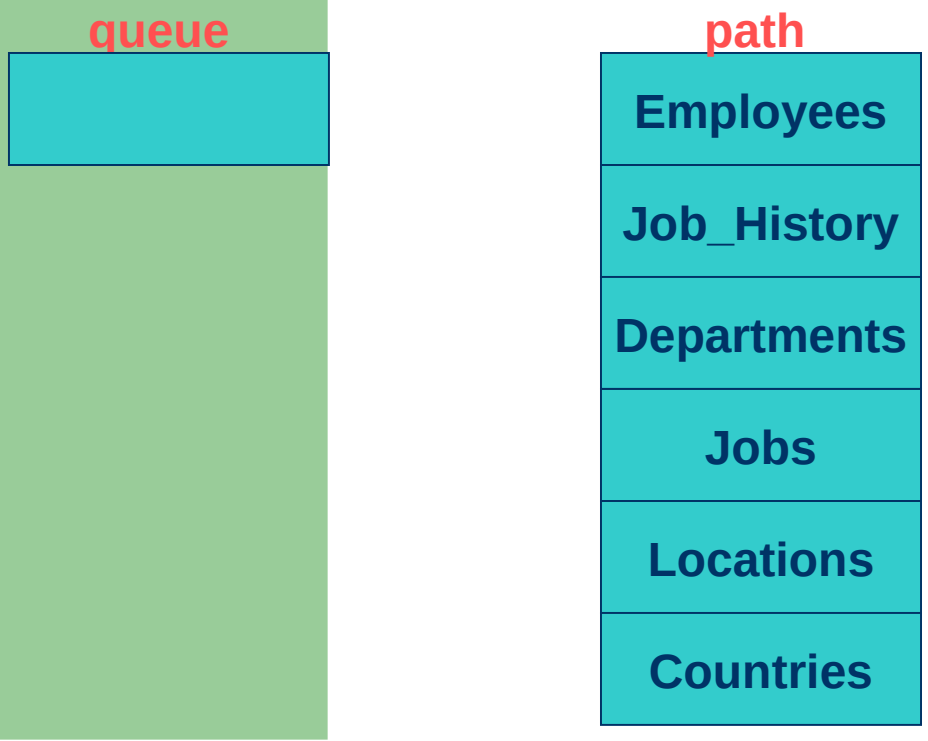

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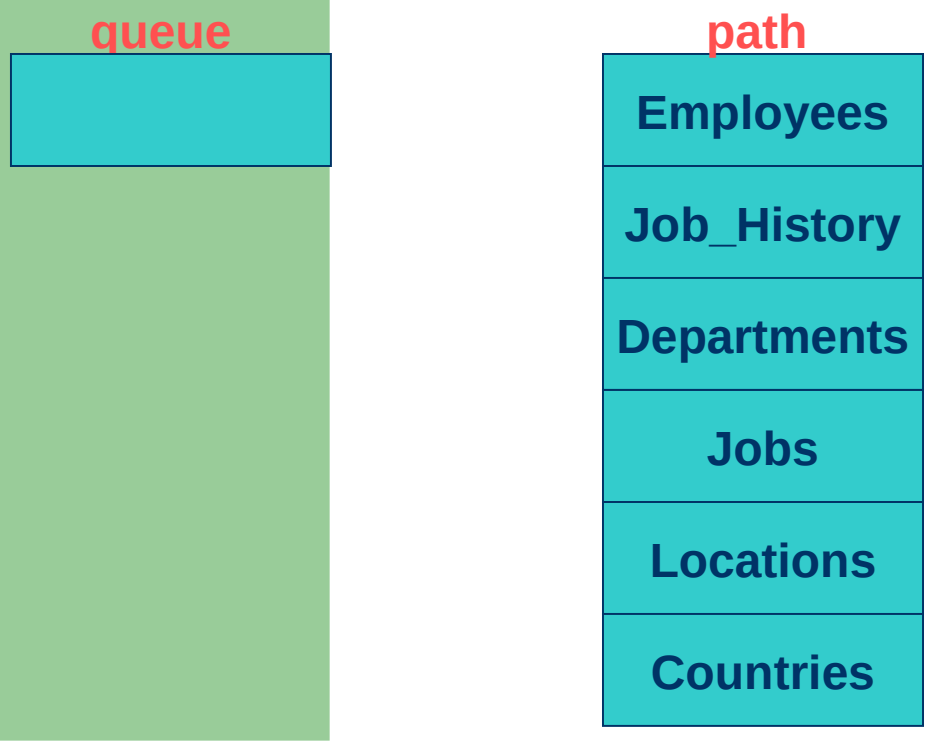

→ insert all the names of base tables from path as vertexes in JoinPathList

create a local buffer buf

insert into buf the first entry from path

for all the remainder entries in path do

take one T_i at a time

JoinPathAdjacentList(T_i) = $T_{[buf]}$

Key(T_i) = getFirstAdjacentListKey(T_i,$T_{[buf]}$)

JoinPathAdjacentList($T_{[buf]}$) = T_i

Key($T_{[buf]}$) = getFirstAdjacentListKey ($T_{[buf]}$,T_i)

$T_{[buf]}$ + = T_i

Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$

vertexes

Employees
Job_History
Deparments
Jobs
Locations
Countries

path

Employees
Job_History
Departments
Jobs
Locations
Countries

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vertexes

Employees
Job_History
Deparments
Jobs
Locations
Countries

buf

path

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Job_History
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vertexes

- Employees
- Job_History
- Deparments
- Jobs
- Locations
- Countries

buf

- Employees

path

- Employees
- Job_History
- Departments
- Jobs
- Locations
- Countries

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vertexes

- Employees
- Job_History
- Deparments
- Jobs
- Locations
- Countries

buf

- Employees

path

- Employees
- Job_History
- Departments
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vertexes

- Employees
- Job_History
- Deparments
- Jobs
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- Countries

buf

- Employees

path

- Employees
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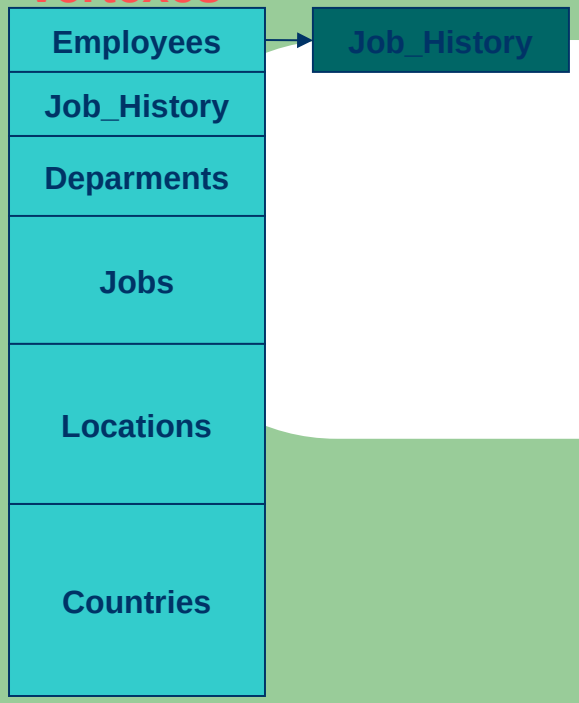
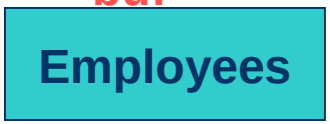
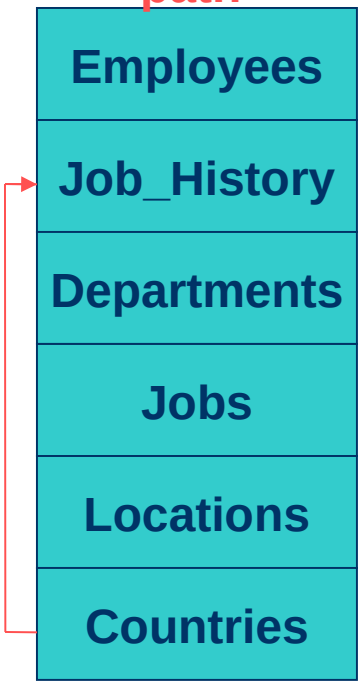
vertexes



buf



path



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vertexes

- Employees
- Job_History
- Deparments
- Jobs
- Locations
- Countries

Job_History	Employees	Employee_Id

buf

Employees

path

- Employees
- Job_History
- Departments
- Jobs
- Locations
- Countries

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$T_{[buf]} += T_i$

$Insert\ NodesList[T_{[buf]}] = T_{[buf]}$

vertexes

- Employees
- Job_History
- Deparments
- Jobs
- Locations
- Countries

Job_History	Employees	Employee_Id
Employees		

buf

Employees

path

- Employees
- Job_History
- Departments
- Jobs
- Locations
- Countries

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$Key(T_{[buf]}) = getFirstAdjacentListKey(T_{[buf]}, T_i)$

$T_{[buf]} += T_i$

$Insert\ NodesList[T_{[buf]}] = T_{[buf]}$

vertexes

Employees	Job_History	Employees	Employee_Id
Job_History	Employees	Job_History	Employee_Id
Deparments			
Jobs			
Locations			
Countries			

buf

Employees

path

Employees
Job_History
Departments
Jobs
Locations
Countries

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vertexes

Employees
Job_History
Deparments
Jobs
Locations
Countries

Job_History	Employees	Employee_Id
Employees	Job_History	Employee_Id

buf

Employees
Job_History

path

Employees
Job_History
Departments
Jobs
Locations
Countries

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vertexes

- Employees
- Job_History
- Deparments
- Jobs
- Locations
- Countries
- Employees Job_History

Job_History	Employees	Employee_Id
Employees	Job_History	Employee_Id

buf

Employees
Job_History

path

- Employees
- Job_History
- Departments
- Jobs
- Locations
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$T_{[buf]} += T_i$

$Insert\ NodesList[T_{[buf]}] = T_{[buf]}$

vertexes

Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History

Job_History	Employees	Employee_Id
Employees	Job_History	Employee_Id

buf

Employees Job_History

path

Employees
Job_History
Departments
Jobs
Locations
Countries

insert all the names of base tables from path as vertexes in JoinPathList

create a local buffer buf

insert into buf the first entry from path

for all the remainder entries in path do

take one T_i at a time

$JoinPathAdjacentList(T_i) = T_{[buf]}$

$Key(T_i) = getFirstAdjacentListKey(T_i, T_{[buf]})$

$JoinPathAdjacentList(T_{[buf]}) = T_i$

$Key(T_{[buf]}) = getFirstAdjacentListKey(T_{[buf]}, T_i)$

$T_{[buf]} += T_i$

$Insert\ NodesList[T_{[buf]}] = T_{[buf]}$

vertexes

Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History

Job_History	Employees	Employee_Id
Employees	Job_History	Employee_Id
Employees Job_History		

buf

Employees Job_History

path

Employees
Job_History
Departments
Jobs
Locations
Countries

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$Insert\ NodesList[T_{[buf]}] = T_{[buf]}$

vertexes

Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History

Job_History	Employees	Employee_Id
Employees	Job_History	Employee_Id
Employees Job_History	Departments	Department_Id

buf

Employees Job_History

path

Employees
Job_History
Departments
Jobs
Locations
Countries

insert all the names of base tables from path as vertexes in JoinPathList

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$T_{[buf]}$ + = T_i

Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$

vertexes

Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History

Job_History	Employees	Employee_Id
Employees	Job_History	Employee_Id
Employees Job_History	Departments	Department_Id

Departments

buf

Employees Job_History

path

Employees
Job_History
Departments
Jobs
Locations
Countries

insert all the names of base tables from path as vertexes in JoinPathList

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Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$

vertexes

Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History

Job_History	Employees	Employee_Id
Employees	Job_History	Employee_Id
Employees Job_History	Departments	Department_Id
Departments	Employees	Department_Id

buf

Employees Job_History

path

Employees
Job_History
Departments
Jobs
Locations
Countries

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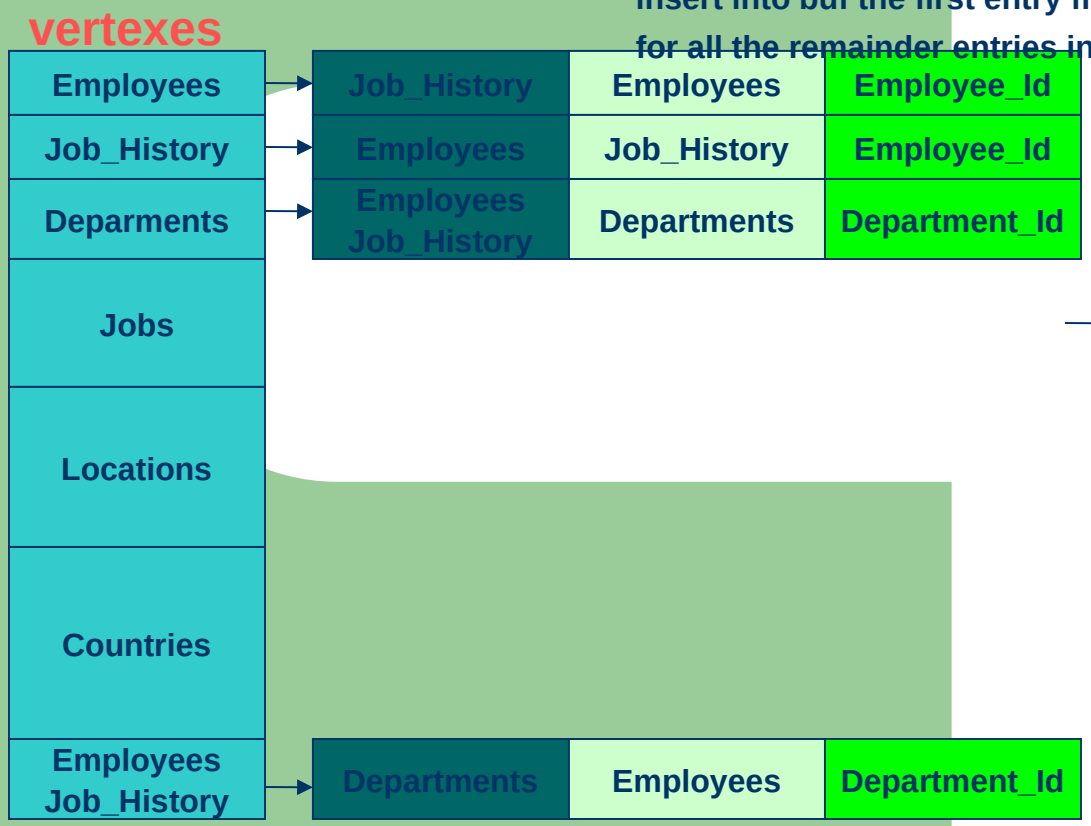
Key($T_{[buf]}$) = getFirstAdjacentListKey ($T_{[buf]}$,T_i)

$T_{[buf]}$ + = T_i

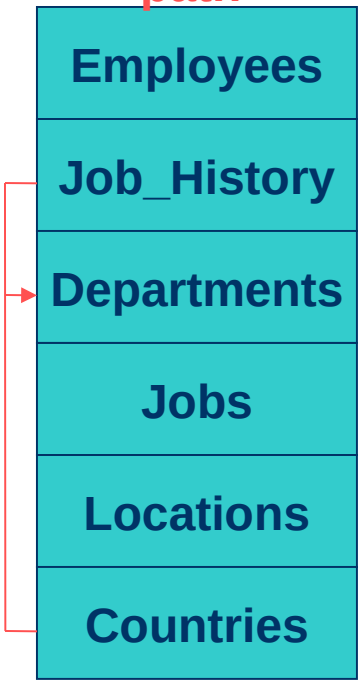
Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$



buf

Employees
Job_History
Departments

path



insert all the names of base tables from path as vertexes in JoinPathList

create a local buffer buf

insert into buf the first entry from path

for all the remainder entries in path do

take one T_i at a time

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JoinPathAdjacentList($T_{[buf]}$) = T_i

Key($T_{[buf]}$) = getFirstAdjacentListKey ($T_{[buf]}$,T_i)

$T_{[buf]}$ + = T_i

Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$

vertexes

Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments

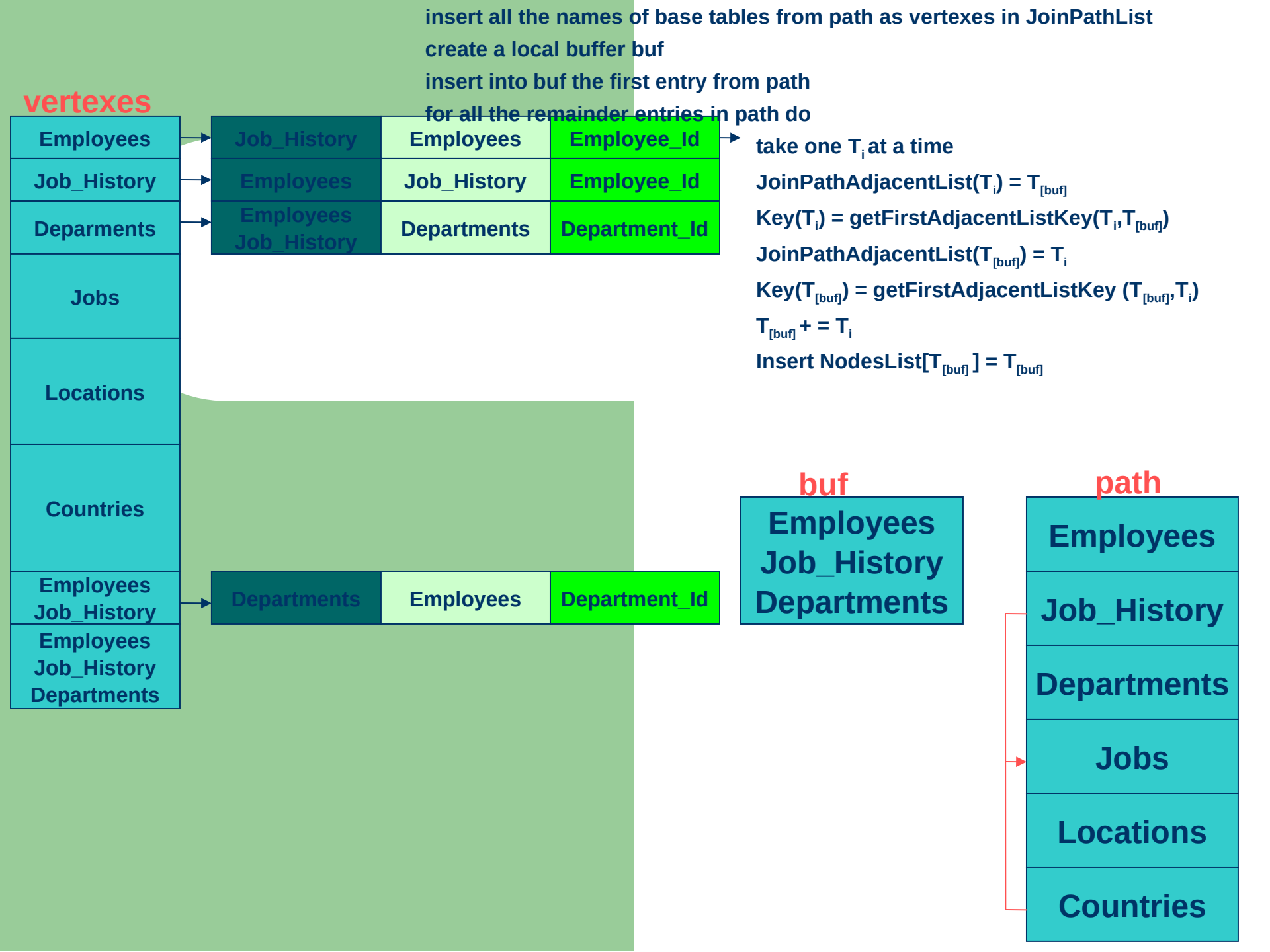
Job_History	Employees	Employee_Id
Employees	Job_History	Employee_Id
Employees Job_History	Departments	Department_Id
Departments	Employees	Department_Id

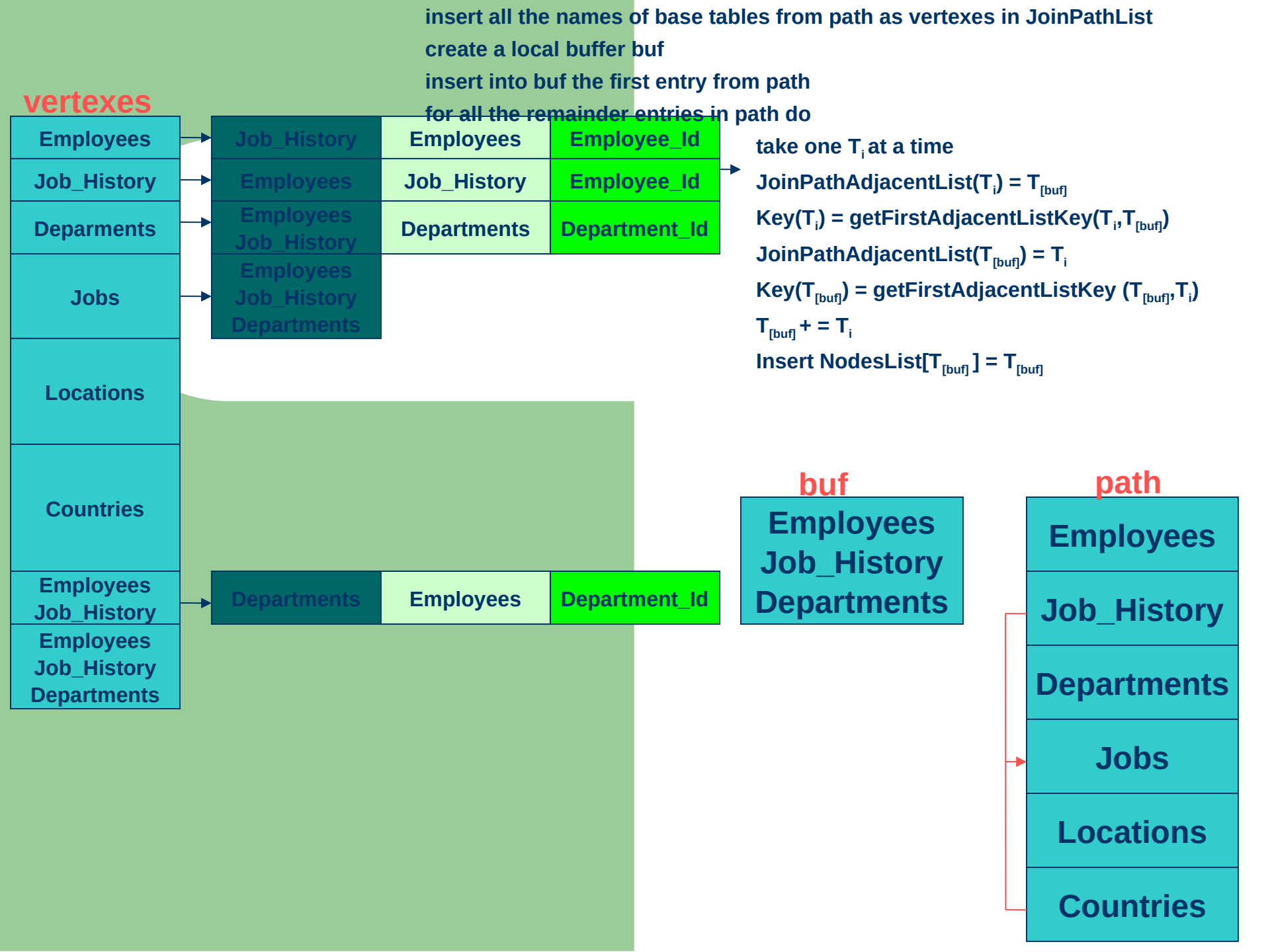
buf

Employees
Job_History
Departments

path

Employees
Job_History
Departments
Jobs
Locations
Countries


insert all the names of base tables from path as vertexes in JoinPathList
create a local buffer buf
insert into buf the first entry from path
for all the remainder entries in path do
take one T_i at a time
JoinPathAdjacentList(T_i) = $T_{[buf]}$
Key(T_i) = getFirstAdjacentListKey(T_i,$T_{[buf]}$)
JoinPathAdjacentList($T_{[buf]}$) = T_i
Key($T_{[buf]}$) = getFirstAdjacentListKey ($T_{[buf]}$,T_i)
$T_{[buf]}$ + = T_i
Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$
vertexes
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Job_History Employees Employee_Id
Employees Job_History Employee_Id
Employees Job_History Departments Department_Id
Departments Employees Department_Id
buf
Employees
Job_History
Departments
path
Employees
Job_History
Departments
Jobs
Locations
Countries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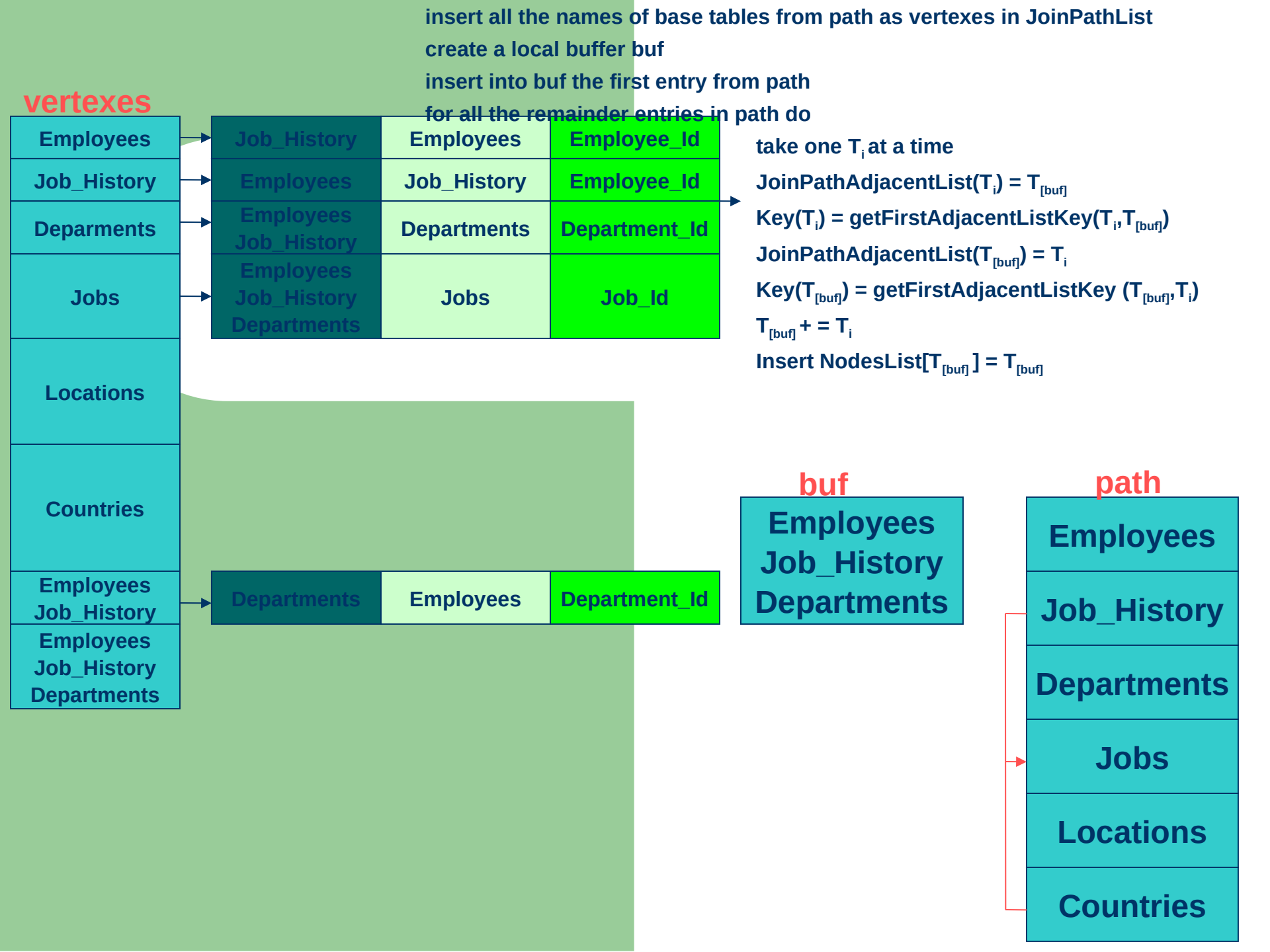
Key($T_{[buf]}$) = getFirstAdjacentListKey ($T_{[buf]}$,T_i)
$T_{[buf]}$ + = T_i
Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$
vertexes
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Job_History
Employees
Employee_Id
Employees
Job_History
Employee_Id
Employees Job_History
Departments
Department_Id
Employees Job_History Departments
Departments
Employees
Department_Id
buf
Employees
Job_History
Departments
path
Employees
Job_History
Departments
Jobs
Locations
Countries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$T_{[buf]}$ + = T_i
Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$
vertexes
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Job_History
Employees
Employee_Id
Employees
Job_History
Employee_Id
Employees Job_History
Departments
Department_Id
Employees Job_History Departments
Jobs
Job_Id
Departments
Employees
Department_Id
buf
Employees
Job_History
Departments
path
Employees
Job_History
Departments
Jobs
Locations
Countries

insert all the names of base tables from path as vertexes in JoinPathList

create a local buffer buf

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$T_{[buf]}$ + = T_i

Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$

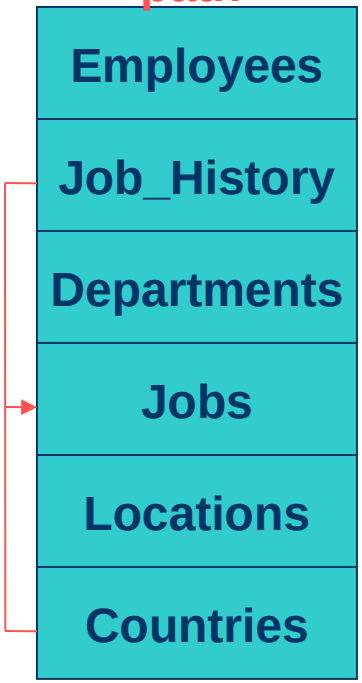
vertexes

Employees	Job_History	Employees	Employee_Id
Job_History	Employees	Job_History	Employee_Id
Deparments	Employees Job_History	Departments	Department_Id
Jobs	Employees Job_History Departments	Jobs	Job_Id
Locations			
Countries			
Employees Job_History	Departments	Employees	Department_Id
Employees Job_History Departments	Jobs		

buf

Employees
Job_History
Departments

path



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$T_{[buf]}$ + = T_i

Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$

vertexes

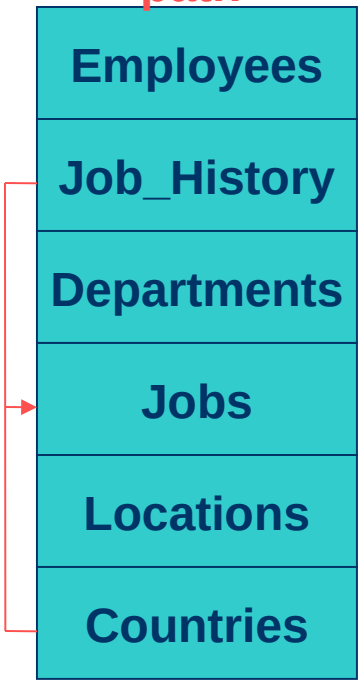
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments

Job_History	Employees	Employee_Id
Employees	Job_History	Employee_Id
Employees Job_History	Departments	Department_Id
Employees Job_History Departments	Jobs	Job_Id
Departments	Employees	Department_Id
Jobs	Job_History	Job_Id

buf

Employees
Job_History
Departments

path



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$T_{[buf]}$ + = T_i

Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$

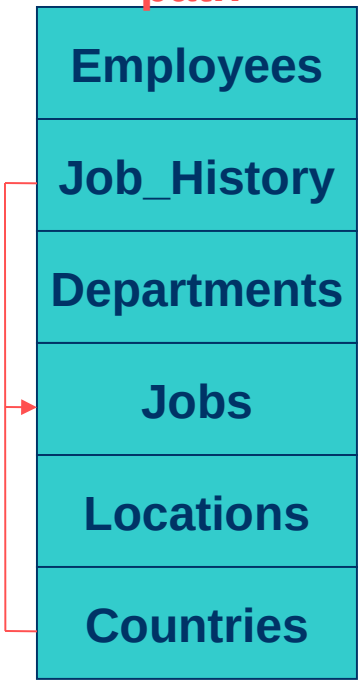
vertexes

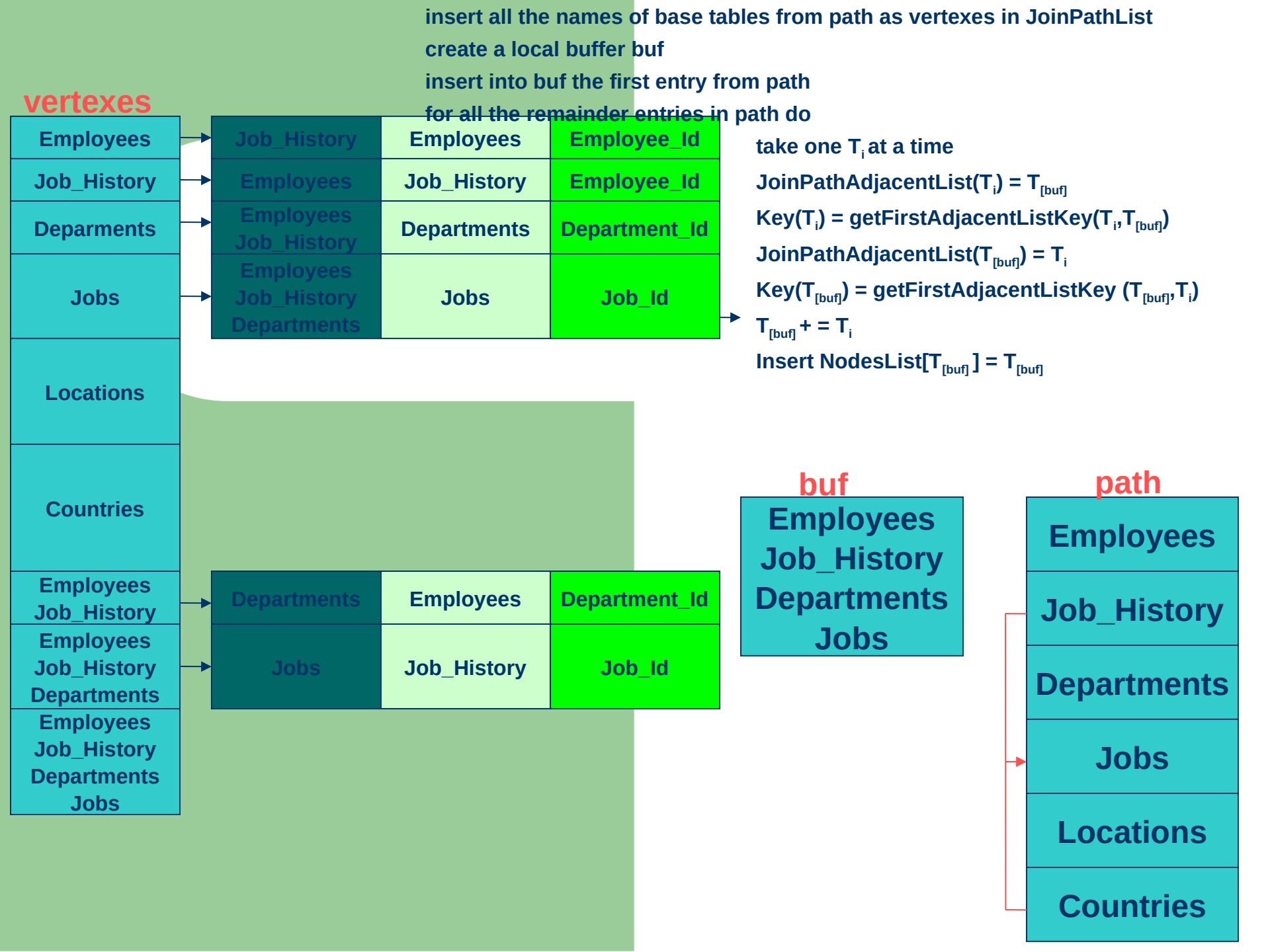
Employees	Job_History	Employees	Employee_Id
Job_History	Employees	Job_History	Employee_Id
Deparments	Employees Job_History	Departments	Department_Id
Jobs	Employees Job_History Departments	Jobs	Job_Id
Locations			
Countries			
Employees Job_History	Departments	Employees	Department_Id
Employees Job_History Departments	Jobs	Job_History	Job_Id

buf

Employees
Job_History
Departments
Jobs

path

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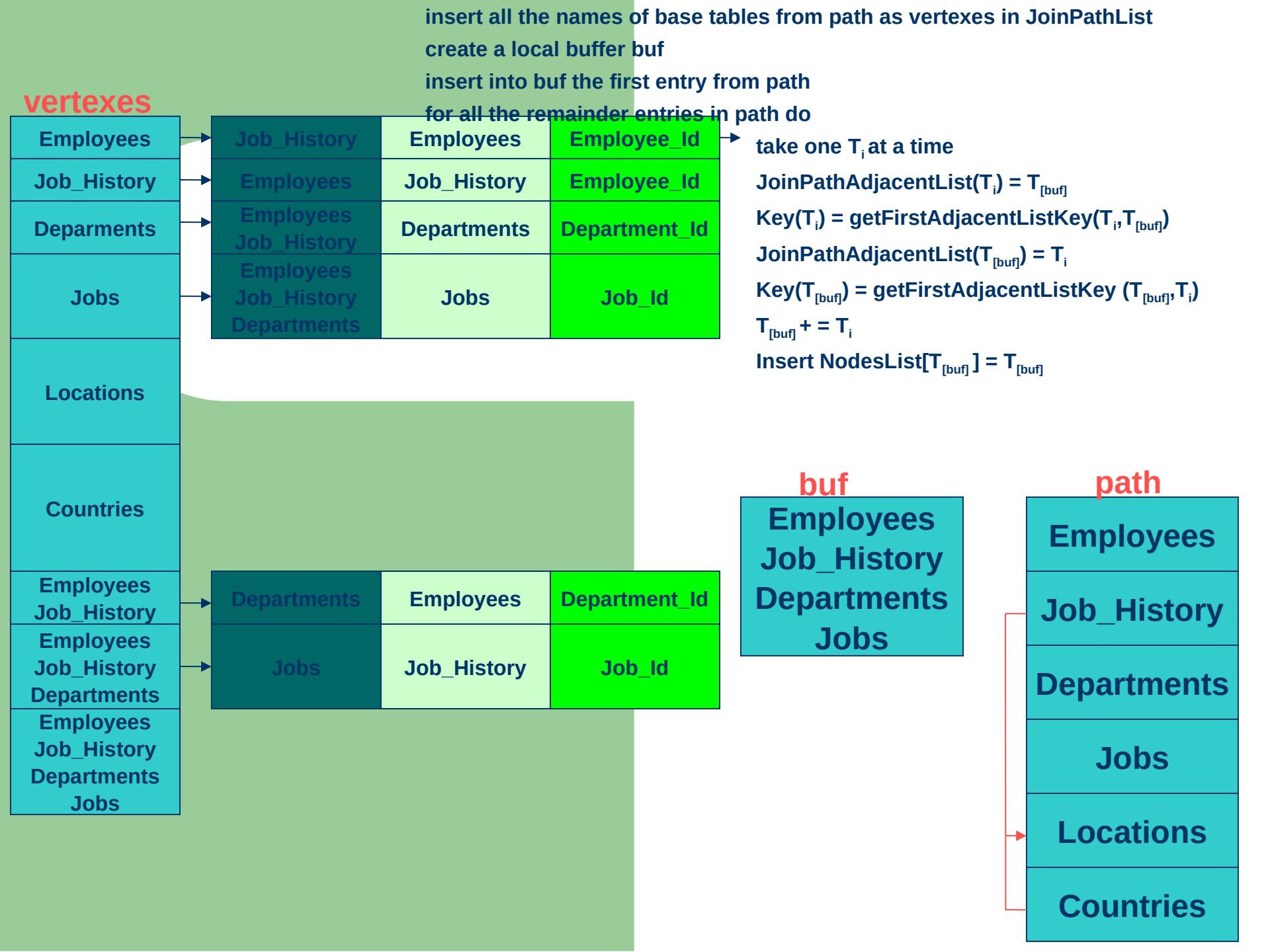
Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$
vertexes
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Job_History
Employees
Employee_Id
Employees
Job_History
Employee_Id
Employees Job_History
Departments
Department_Id
Employees Job_History Departments
Jobs
Job_Id
Departments
Employees
Department_Id
Jobs
Job_History
Job_Id
buf
Employees
Job_History
Departments
Jobs
path
Employees
Job_History
Departments
Jobs
Locations
Countries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vertexes
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Job_History
Employees
Employee_Id
Employees
Job_History
Employee_Id
Employees Job_History
Departments
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Employees Job_History Departments
Jobs
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Employees
Department_Id
Jobs
Job_History
Job_Id
buf
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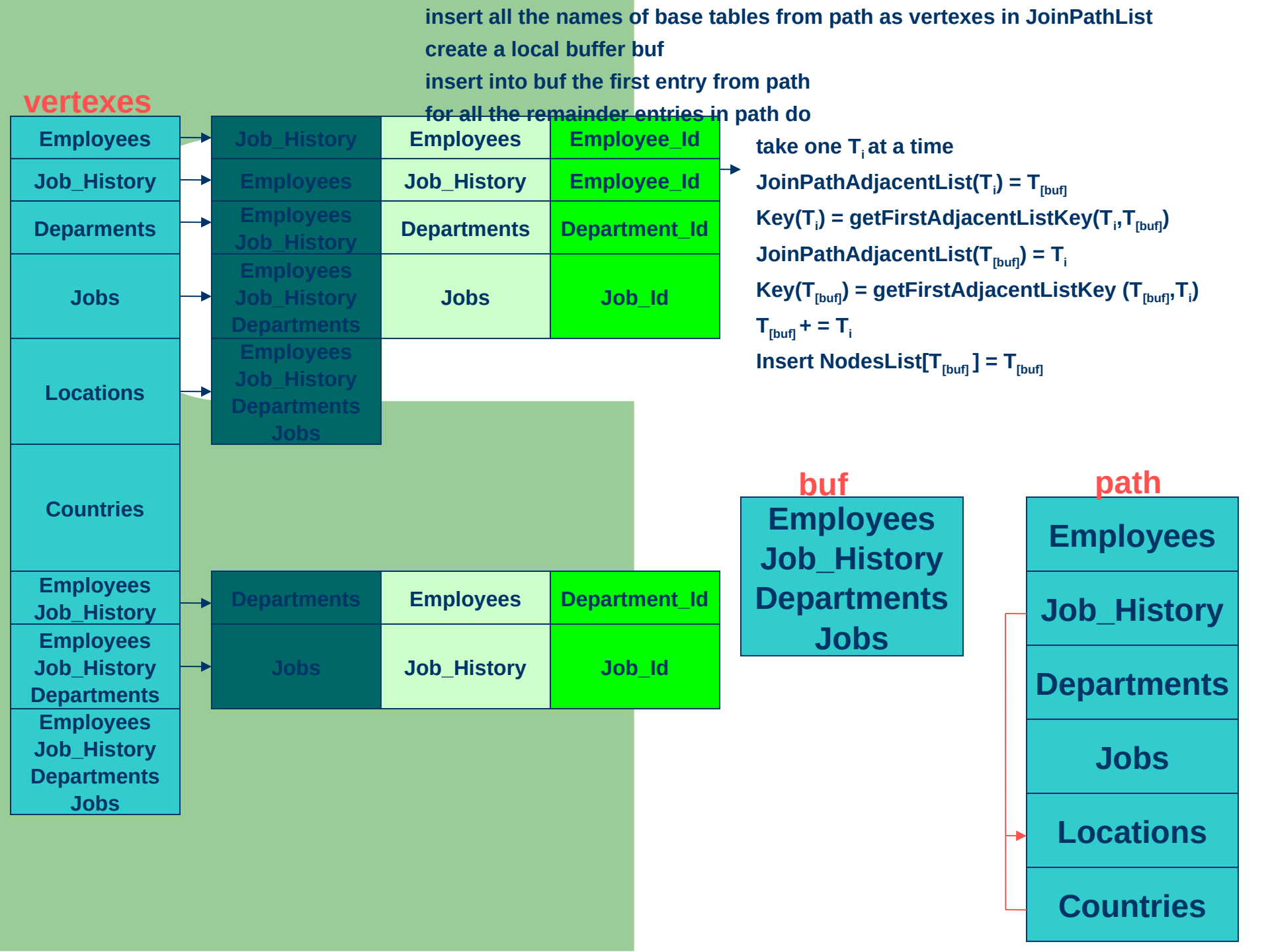
Job_History
Departments
Jobs
path
Employees
Job_History
Departments
Jobs
Locations
Countries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$T_{[buf]}$ + = T_i
Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$
vertexes
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Job_History
Employees
Employee_Id
Employees
Job_History
Employee_Id
Employees Job_History
Departments
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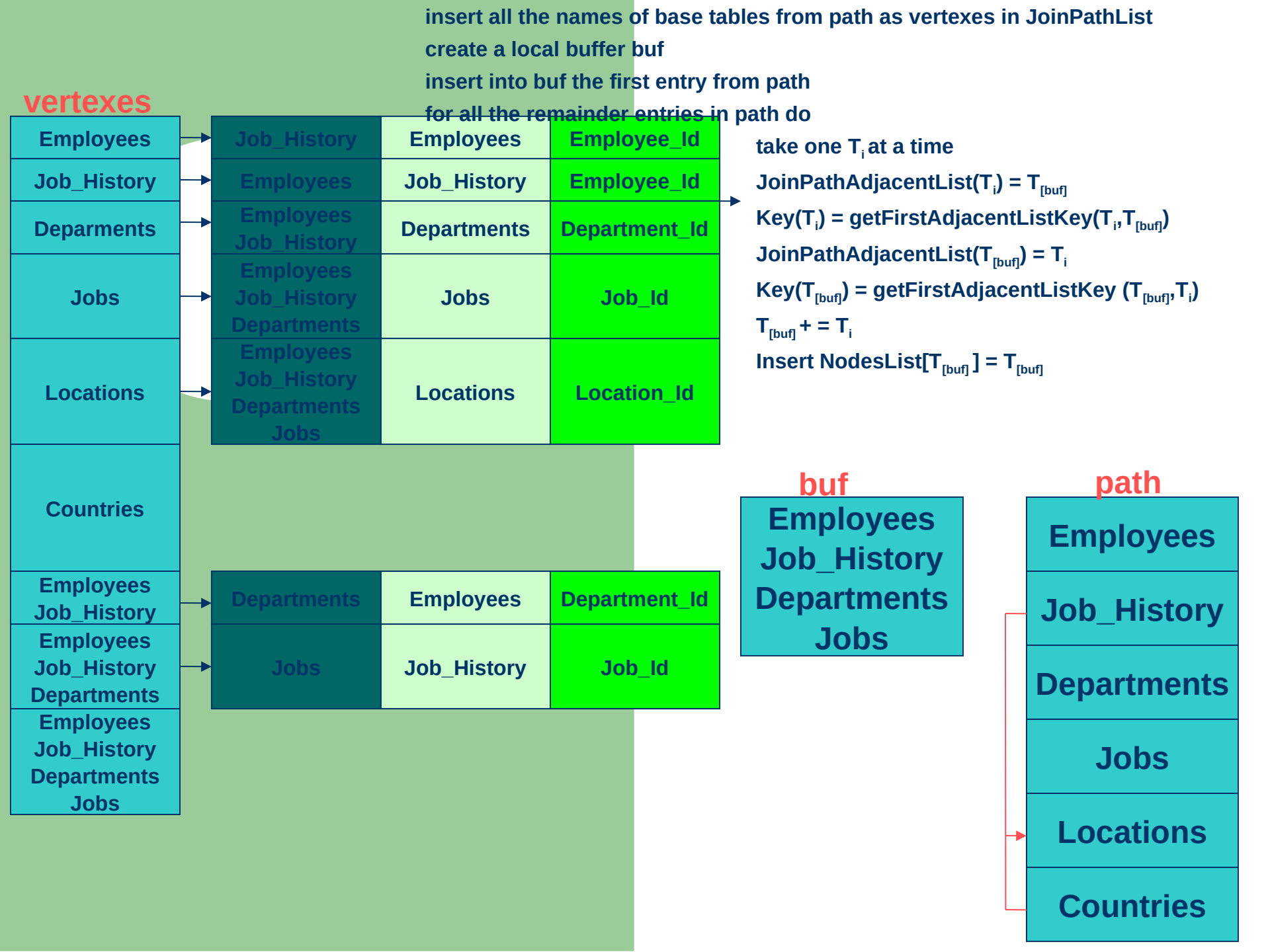
Department_Id
Jobs
Job_History
Job_Id
buf
Employees
Job_History
Departments
Jobs
path
Employees
Job_History
Departments
Jobs
Locations
Countries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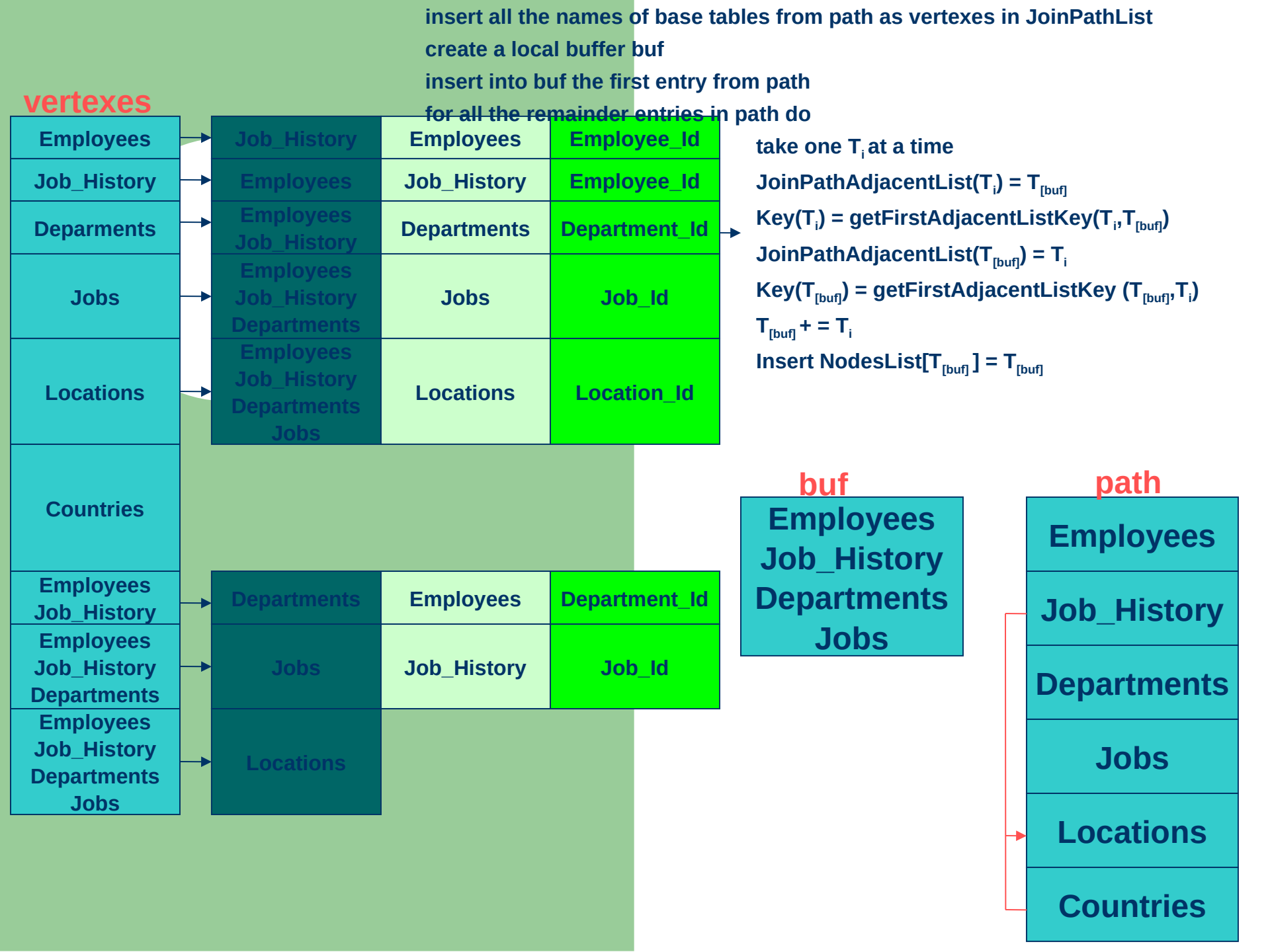
$T_{[buf]}$ + = T_i
Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$
vertexes
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Job_History
Employees
Employee_Id
Employees
Job_History
Employee_Id
Employees Job_History
Departments
Department_Id
Employees Job_History Departments
Jobs
Job_Id
Employees Job_History Departments Jobs
Locations
Location_Id
Departments
Employees
Department_Id
Jobs
Job_History
Job_Id
buf
Employees
Job_History
Departments
Jobs
path
Employees
Job_History
Departments
Jobs
Locations
Countries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create a local buffer buf
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Key($T_{[buf]}$) = getFirstAdjacentListKey ($T_{[buf]}$,T_i)
$T_{[buf]}$ + = T_i
Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$
vertexes
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Job_History
Employees
Employee_Id
Employees
Job_History
Employee_Id
Employees Job_History
Departments
Department_Id
Employees Job_History Departments
Jobs
Job_Id
Employees Job_History Departments Jobs
Locations
Location_Id
Departments
Employees
Department_Id
Jobs
Job_History
Job_Id
Locations
buf
Employees
Job_History
Departments
Jobs
path
Employees
Job_History
Departments
Jobs
Locations
Countries

insert all the names of base tables from path as vertexes in JoinPathList

create a local buffer buf

insert into buf the first entry from path

for all the remainder entries in path do

take one T_i at a time

$JoinPathAdjacentList(T_i) = T_{[buf]}$

$Key(T_i) = getFirstAdjacentListKey(T_i, T_{[buf]})$

$JoinPathAdjacentList(T_{[buf]}) = T_i$

$Key(T_{[buf]}) = getFirstAdjacentListKey(T_{[buf]}, T_i)$

$T_{[buf]} += T_i$

$Insert\ NodesList[T_{[buf]}] = T_{[buf]}$

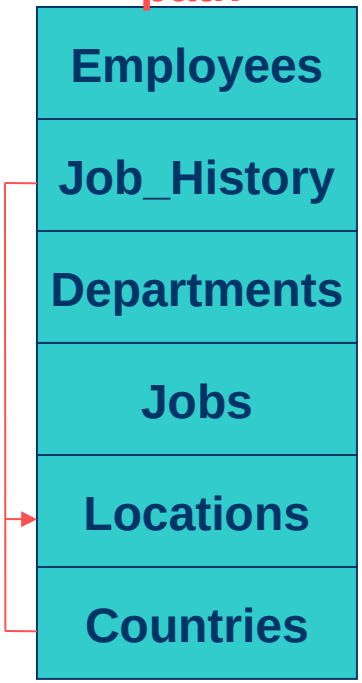
vertexes

Employees	Job_History	Employees	Employee_Id
Job_History	Employees	Job_History	Employee_Id
Deparments	Employees Job_History	Departments	Department_Id
Jobs	Employees Job_History Departments	Jobs	Job_Id
Locations	Employees Job_History Departments Jobs	Locations	Location_Id
Countries			
Employees Job_History	Departments	Employees	Department_Id
Employees Job_History Departments	Jobs	Job_History	Job_Id
Employees Job_History Departments Jobs	Locations	Departments	Location_Id

buf

Employees
Job_History
Departments
Jobs

path



insert all the names of base tables from path as vertexes in JoinPathList

create a local buffer buf

insert into buf the first entry from path

for all the remainder entries in path do

take one T_i at a time

JoinPathAdjacentList(T_i) = $T_{[buf]}$

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JoinPathAdjacentList($T_{[buf]}$) = T_i

Key($T_{[buf]}$) = getFirstAdjacentListKey ($T_{[buf]}$,T_i)

$T_{[buf]}$ + = T_i

Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$

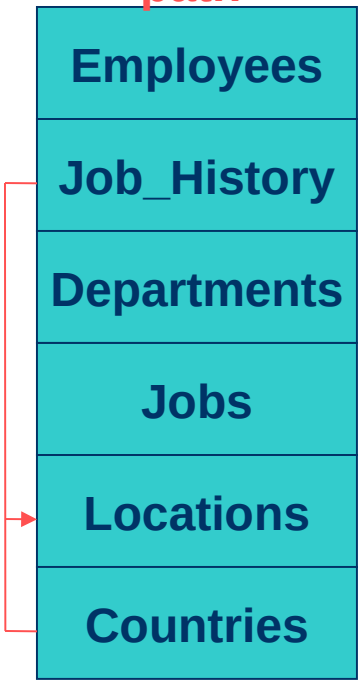
vertexes

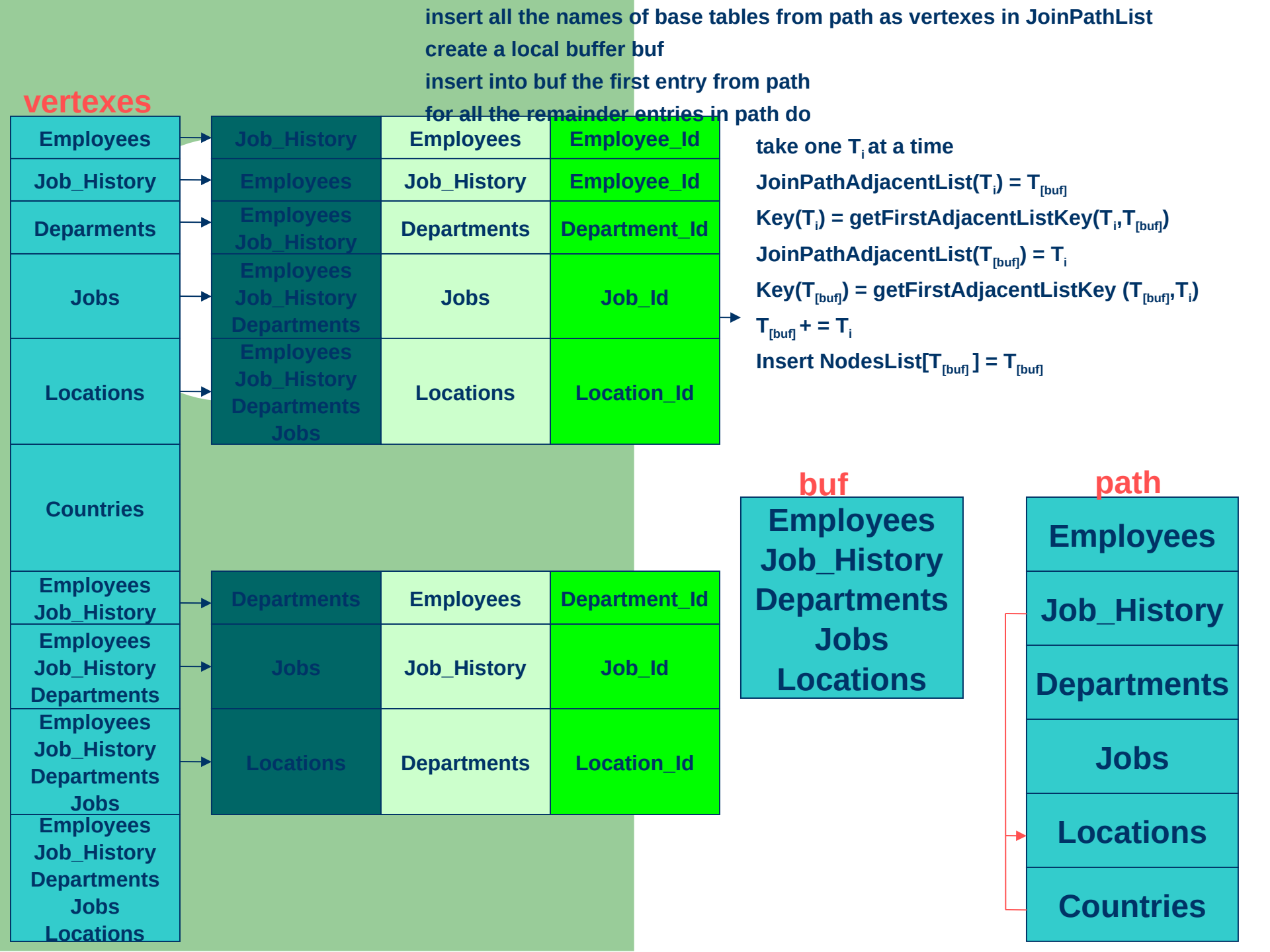
Employees	Job_History	Employees	Employee_Id
Job_History	Employees	Job_History	Employee_Id
Deparments	Employees Job_History	Departments	Department_Id
Jobs	Employees Job_History Departments	Jobs	Job_Id
Locations	Employees Job_History Departments Jobs	Locations	Location_Id
Countries			
Employees Job_History	Departments	Employees	Department_Id
Employees Job_History Departments	Jobs	Job_History	Job_Id
Employees Job_History Departments Jobs	Locations	Departments	Location_Id

buf

Employees
Job_History
Departments
Jobs
Locations

path

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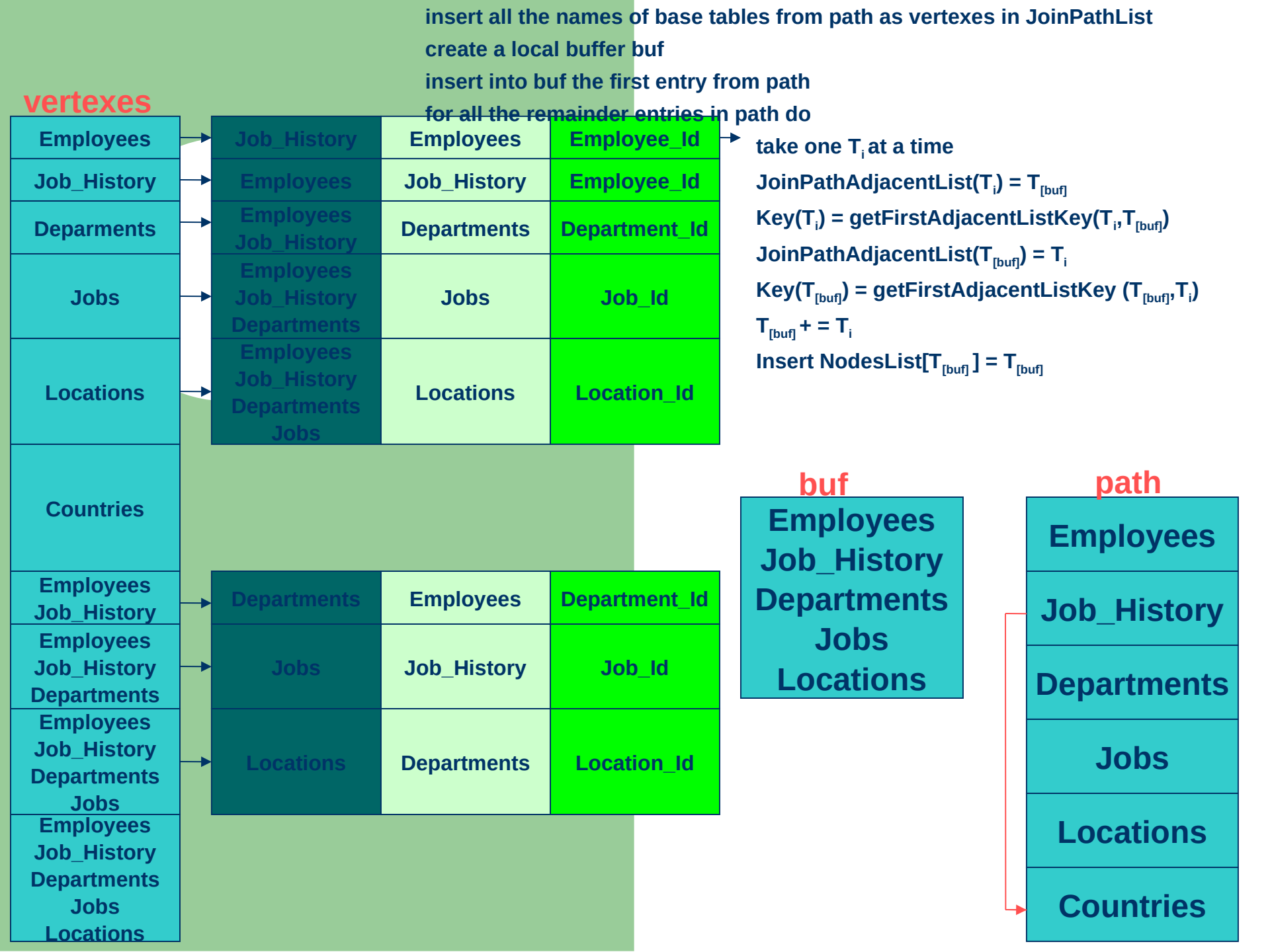
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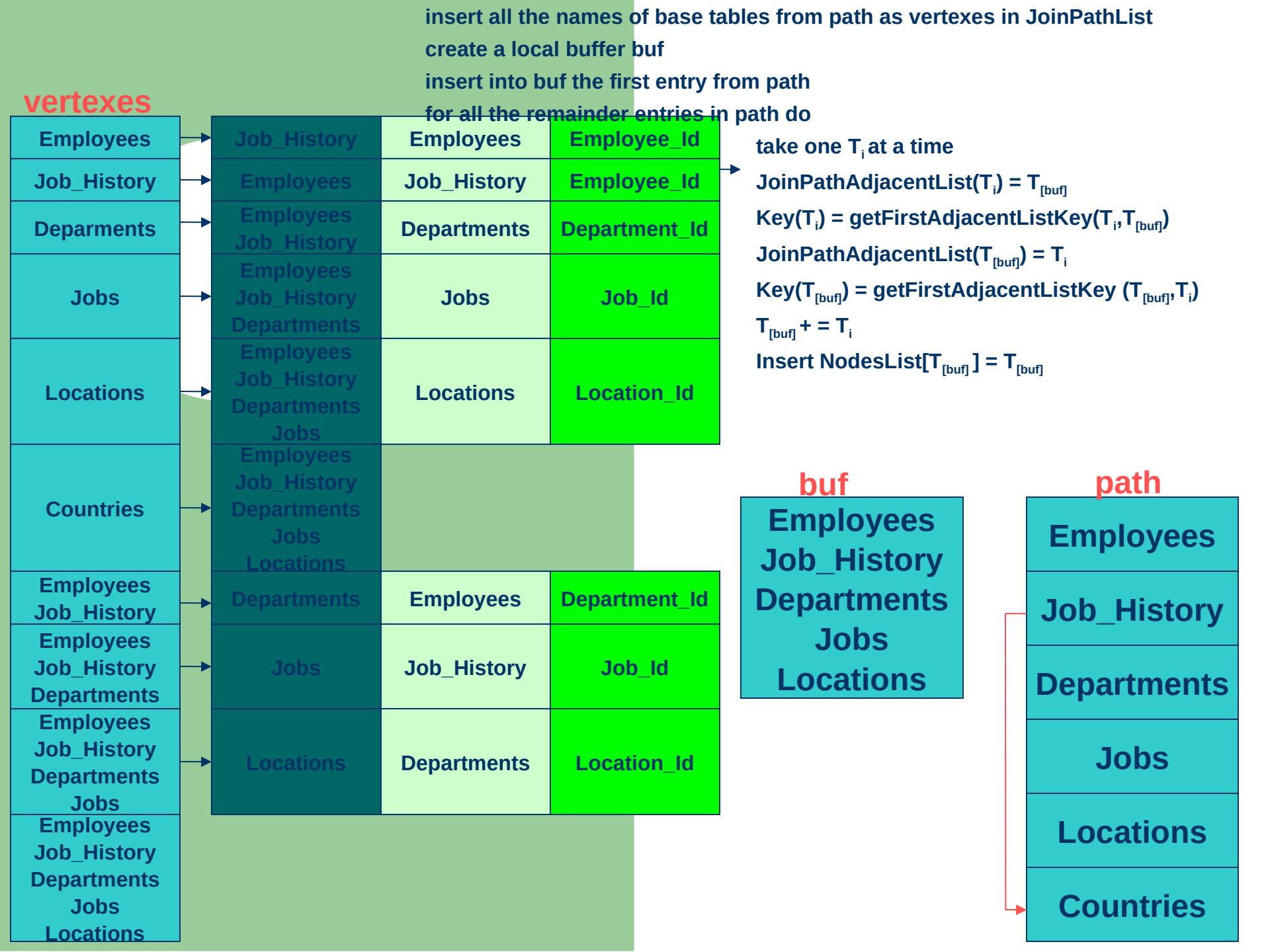
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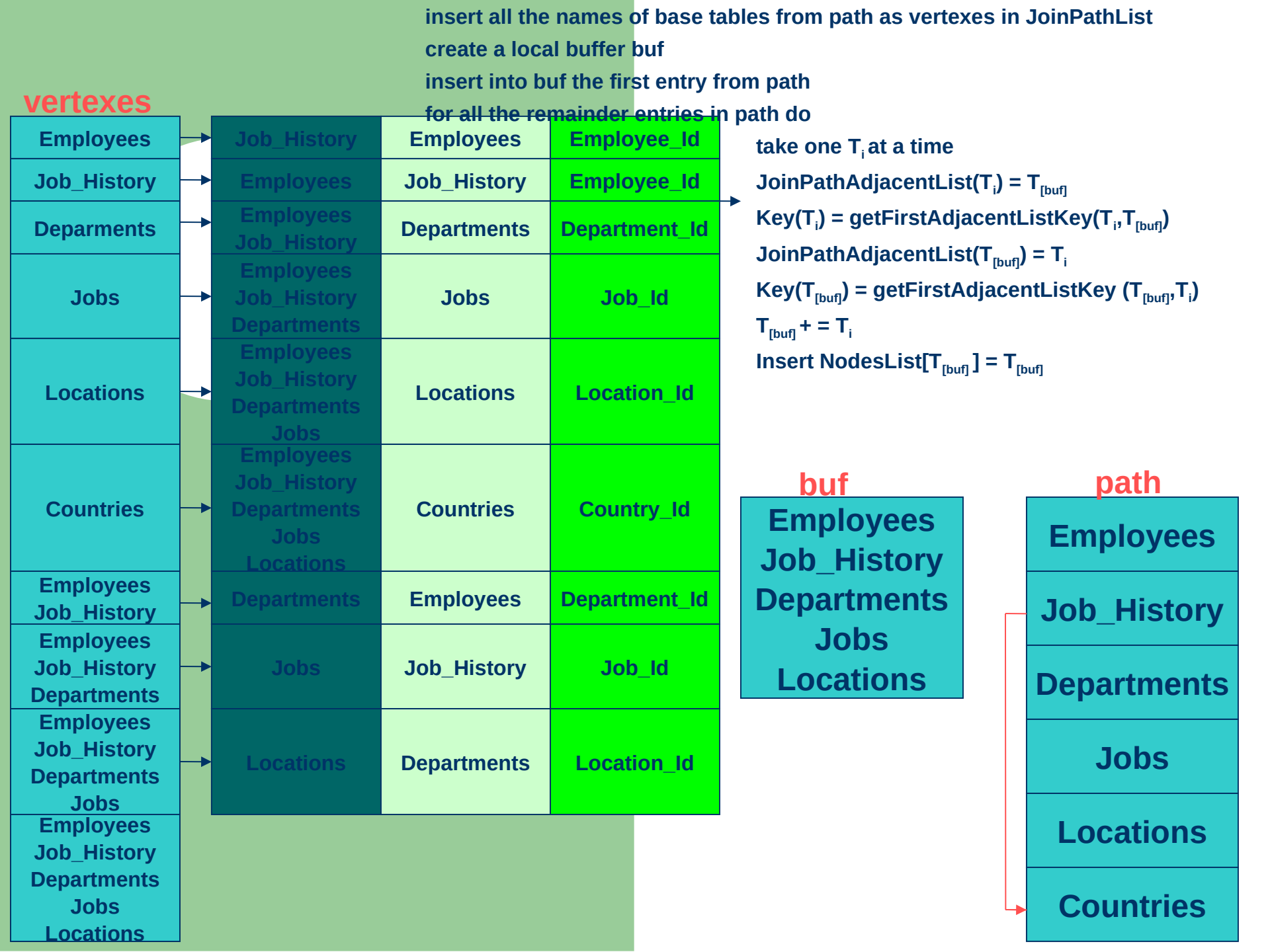
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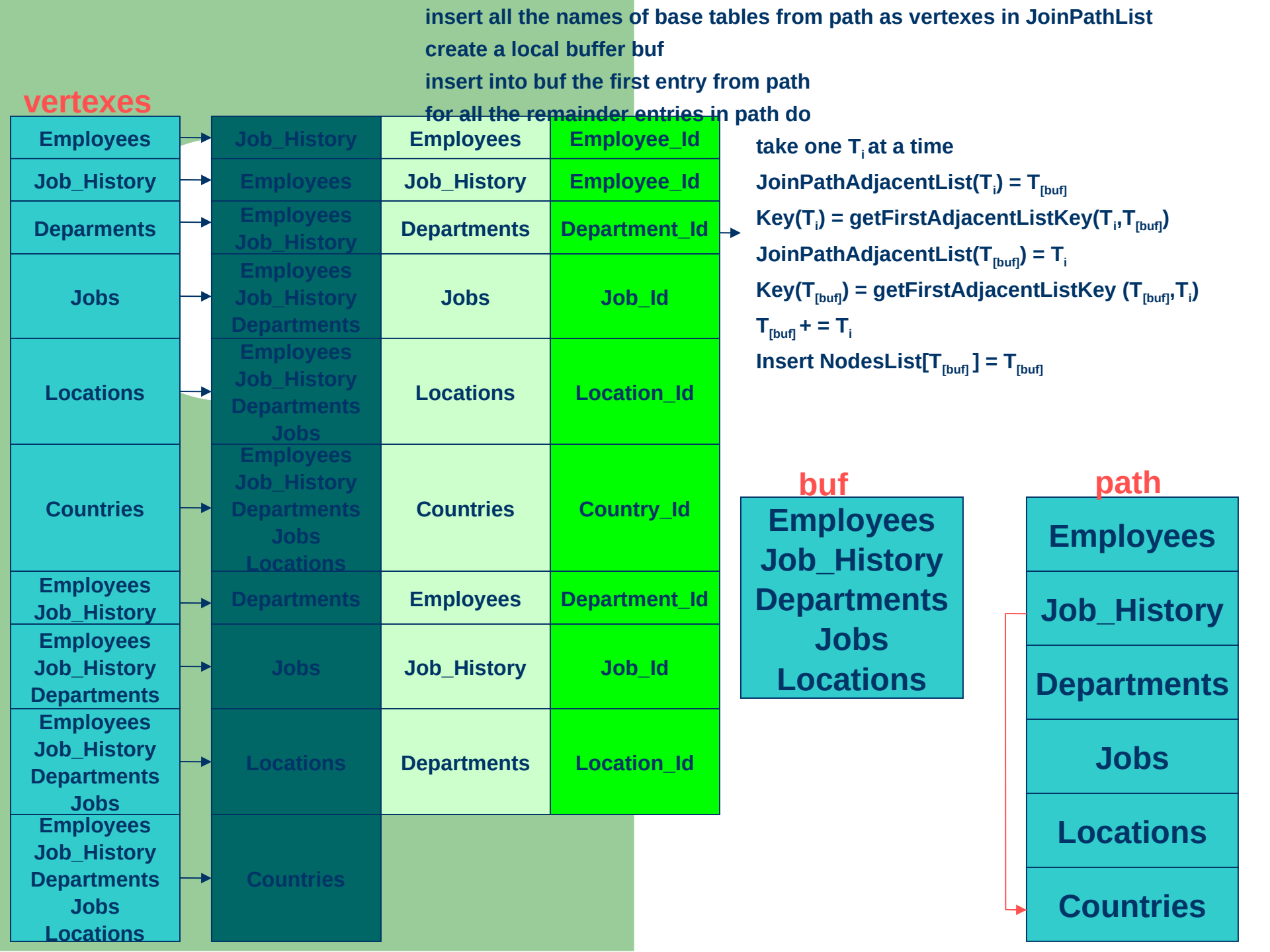
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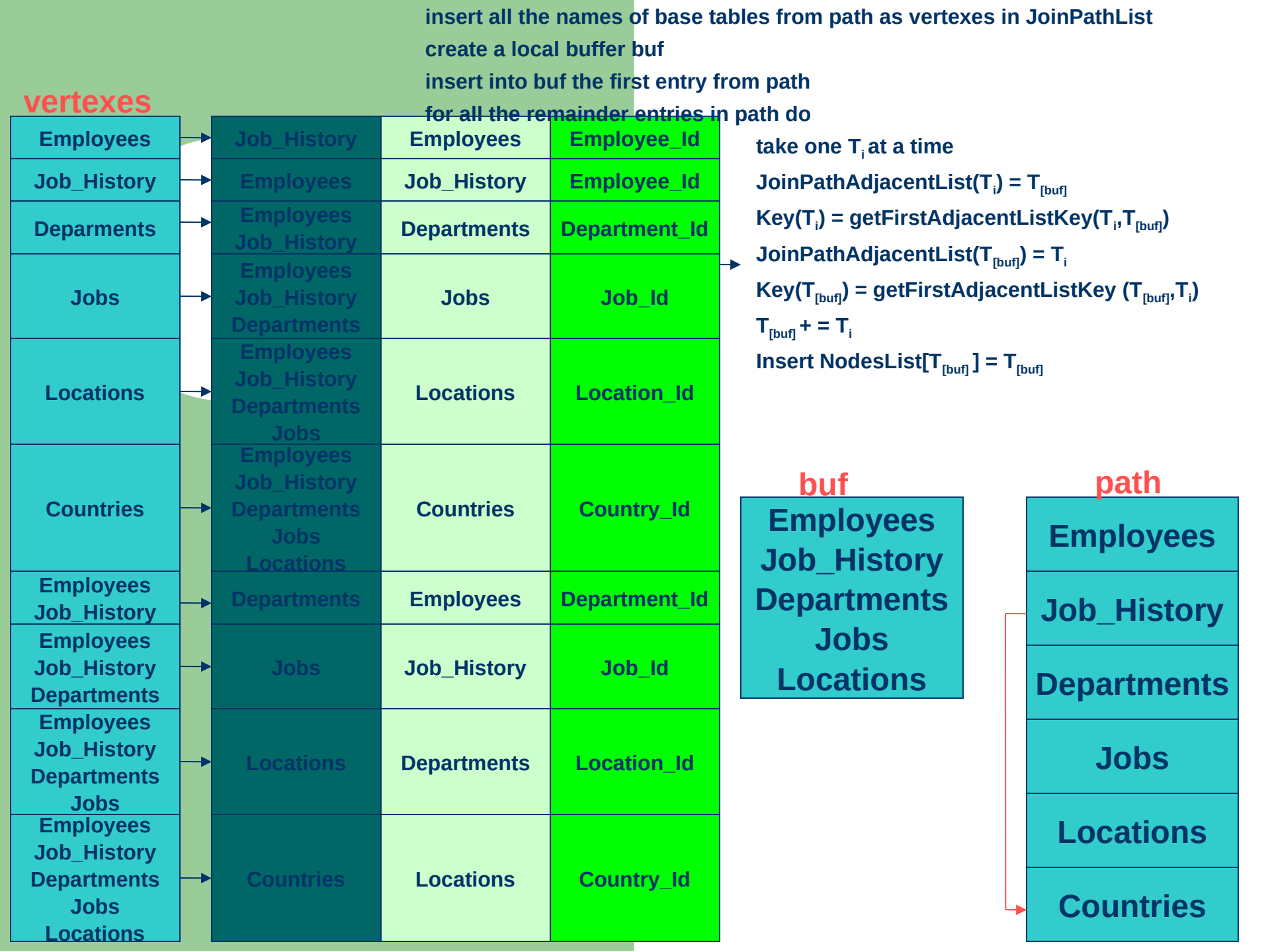
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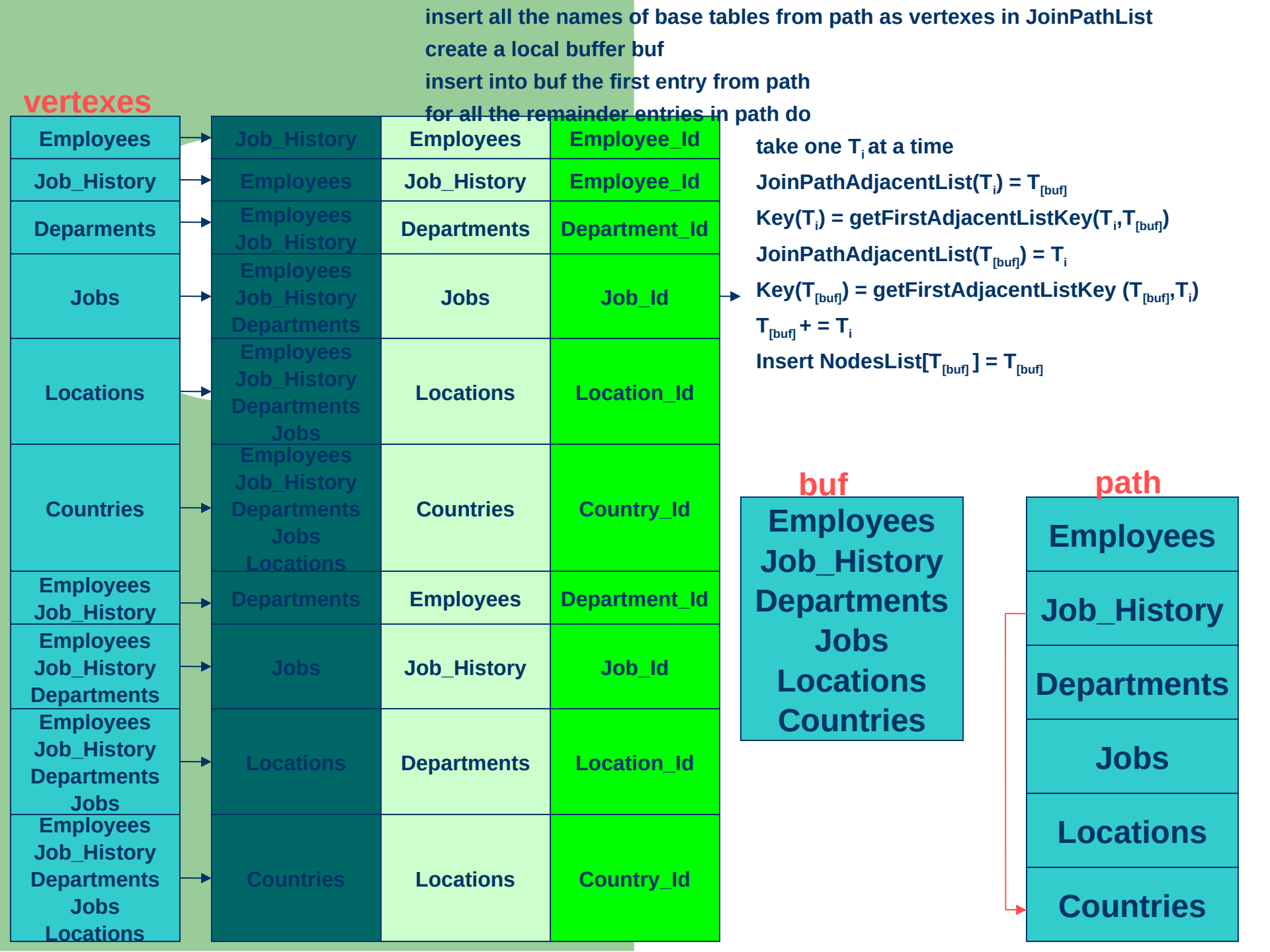
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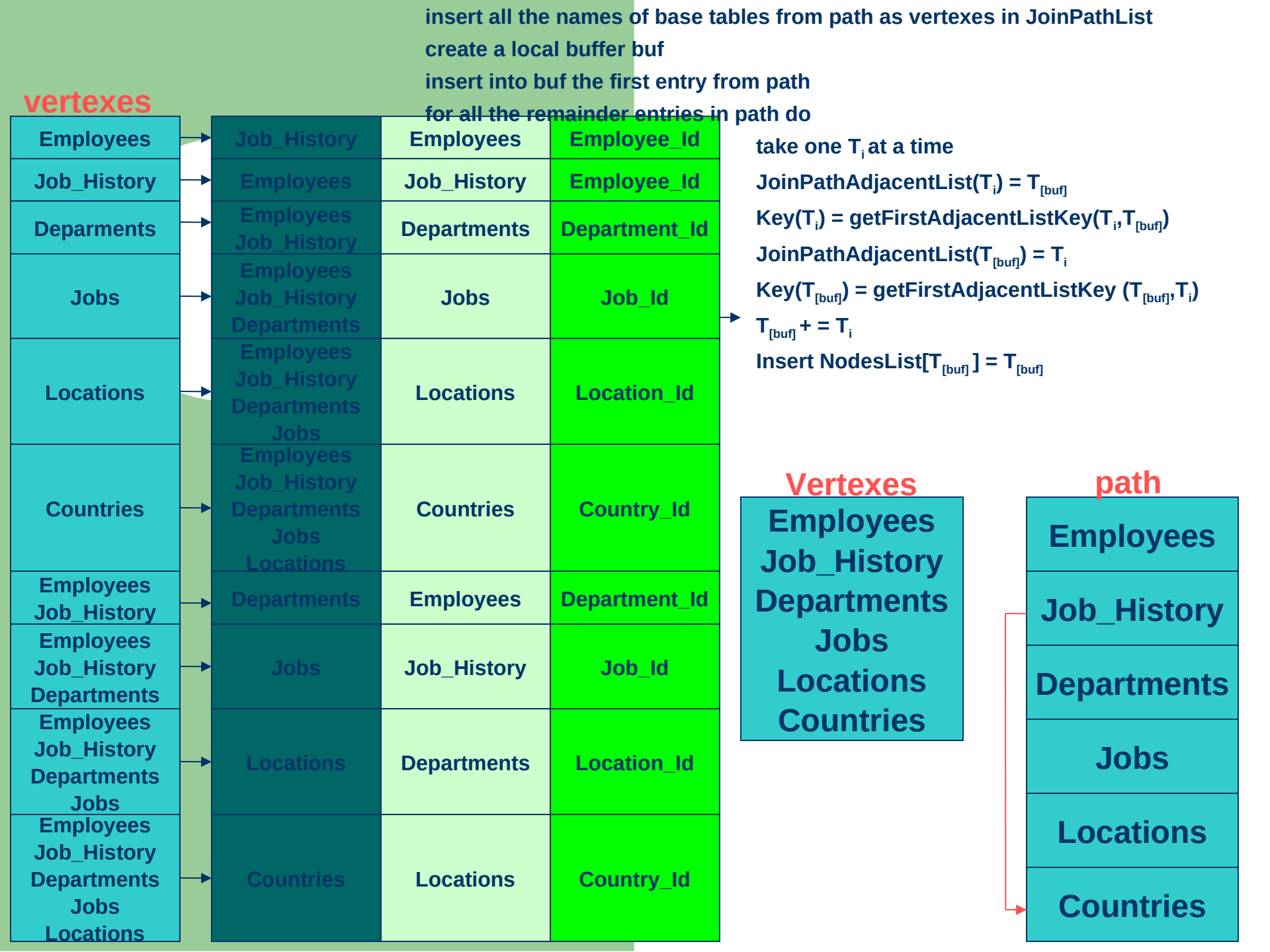
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vertexes
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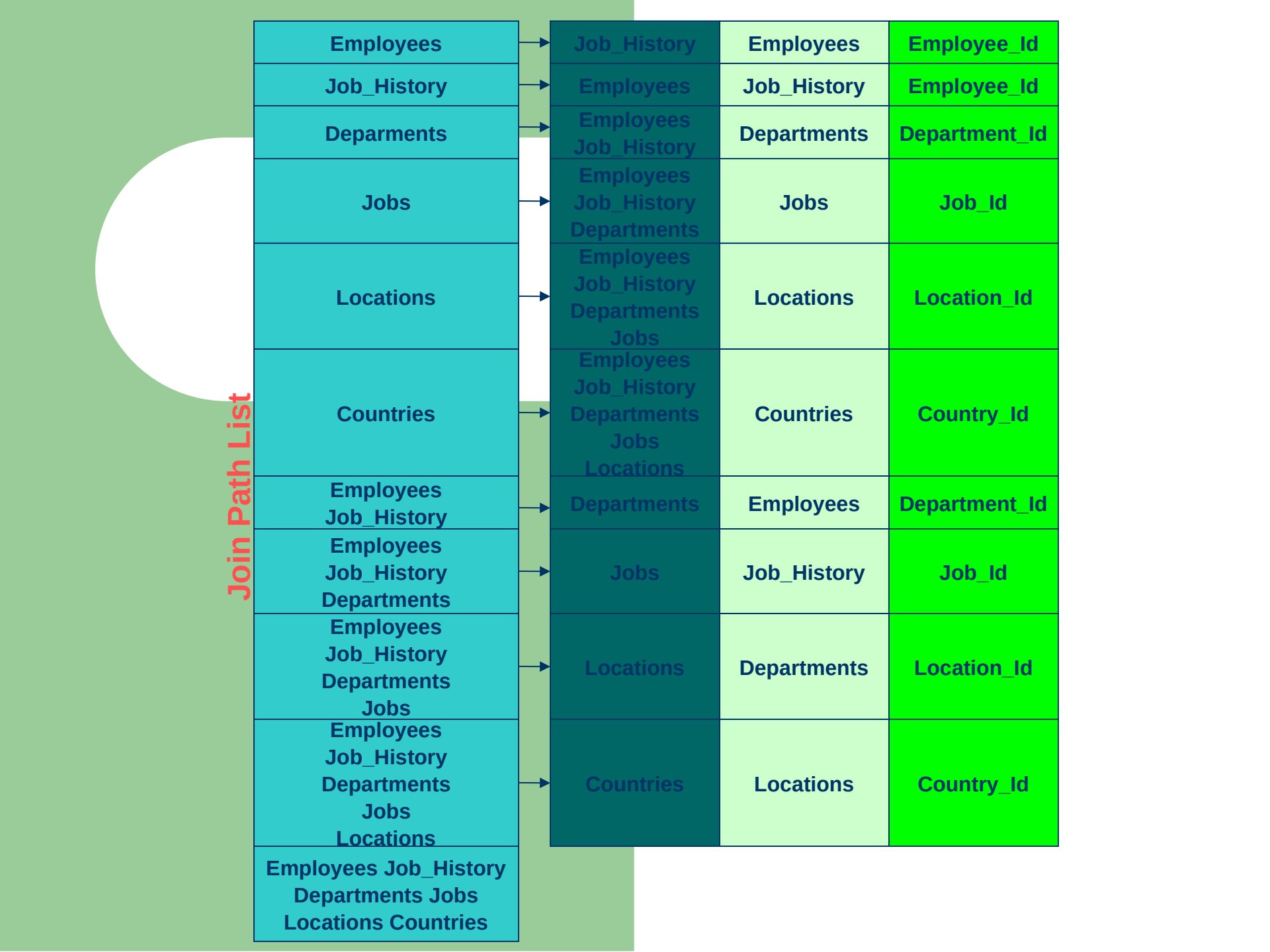
Join Path List
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Jobs
Locations
Countries
Employee_Id
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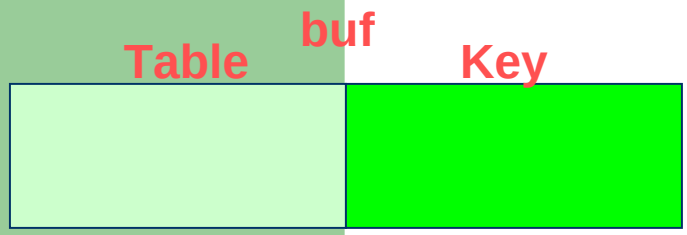
Country_Id
Department_Id
Job_Id
Location_Id
Country_Id

- create a structure buf with 2 fields: Table and Key
  for all the tables in JoinPathList going downward do
    take one $T_{[i]}$ at a time
    for all Base Tables in $T_{[i]}$ do
      take one T_k at a time
      for every buf.Table = T_k do
        if (buf.key != Key($T_{[i]}$)) and (buf.Key not in InheritedKey($T_{[i]}$)) then
        InheritedKey($T_{[i]}$) += buf.key
    if T_l is the table from which comes Key($T_{[i]}$) then
      buf.Table = T_l
      buf.key = Key($T_{[i]}$)



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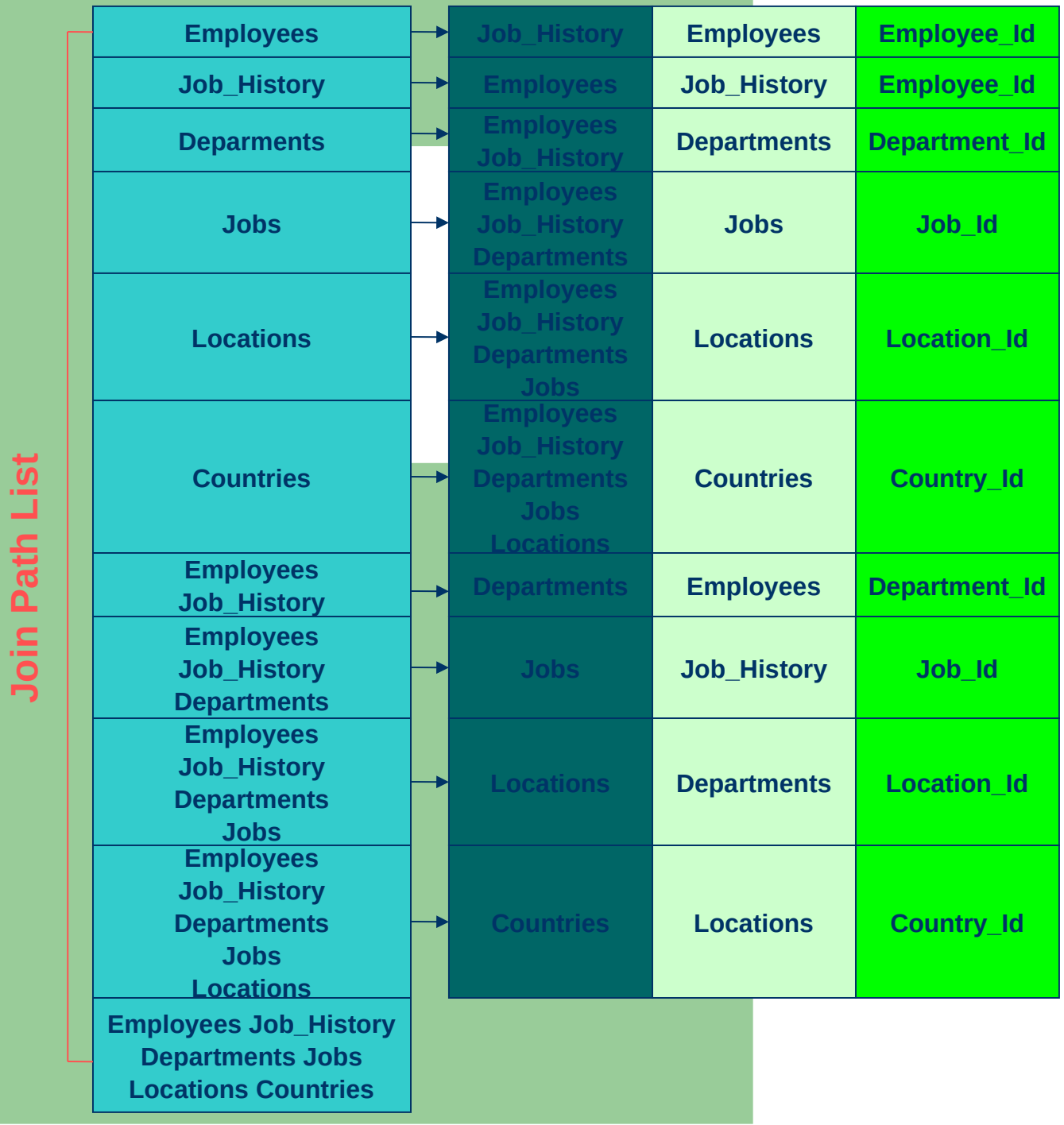
Join Path List
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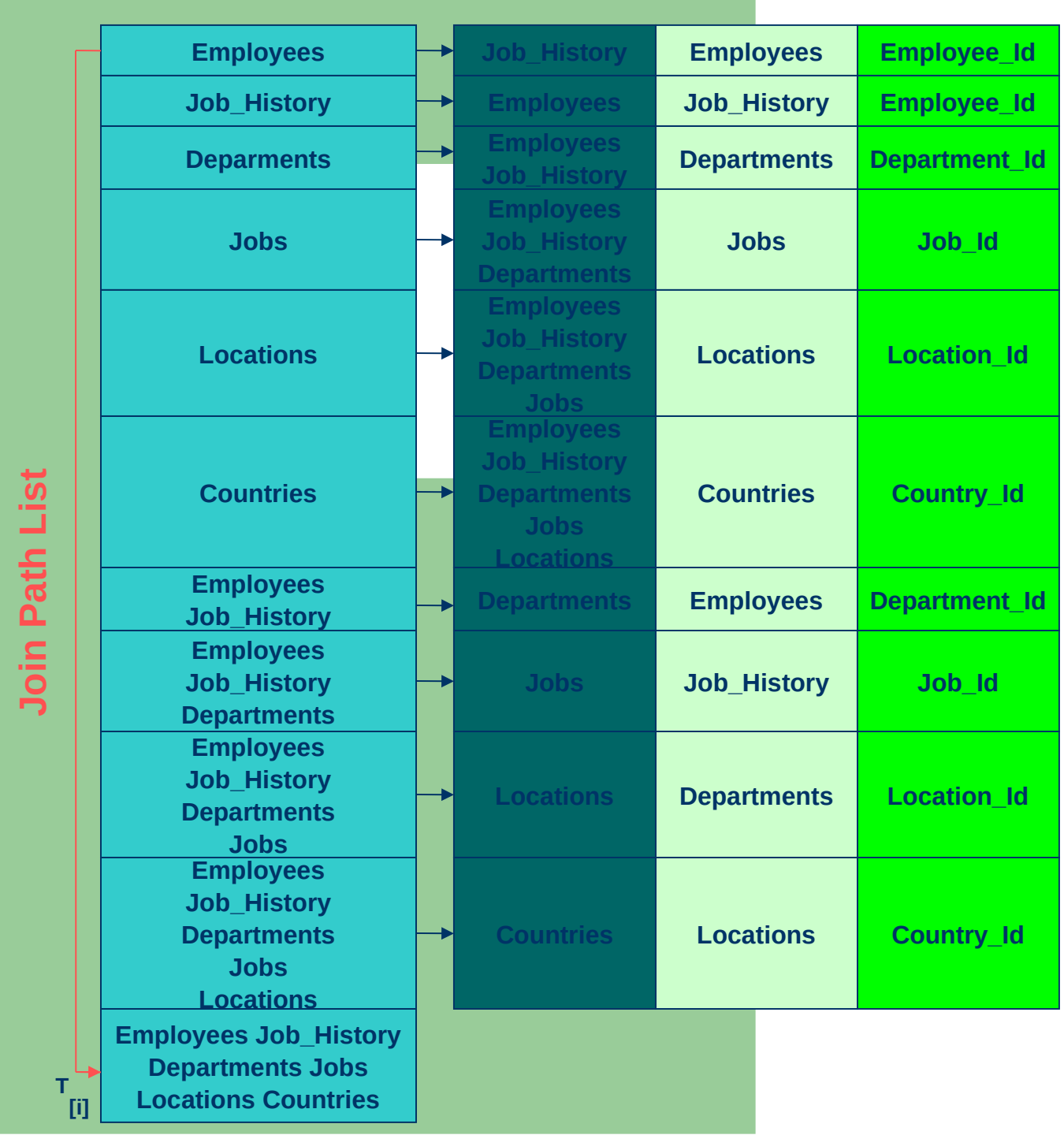
Join Path List
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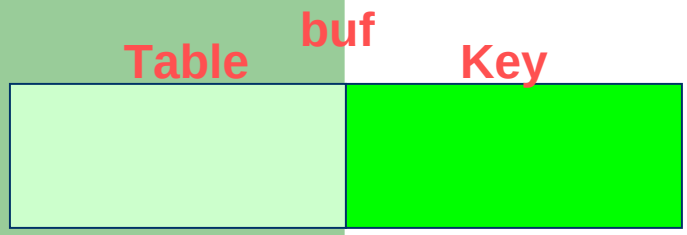

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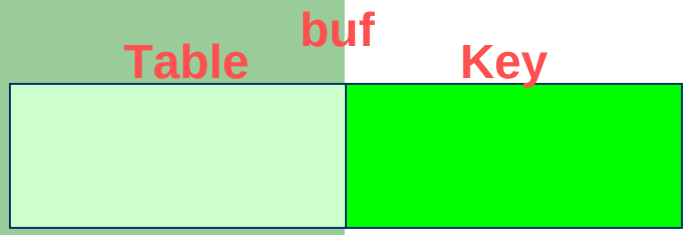

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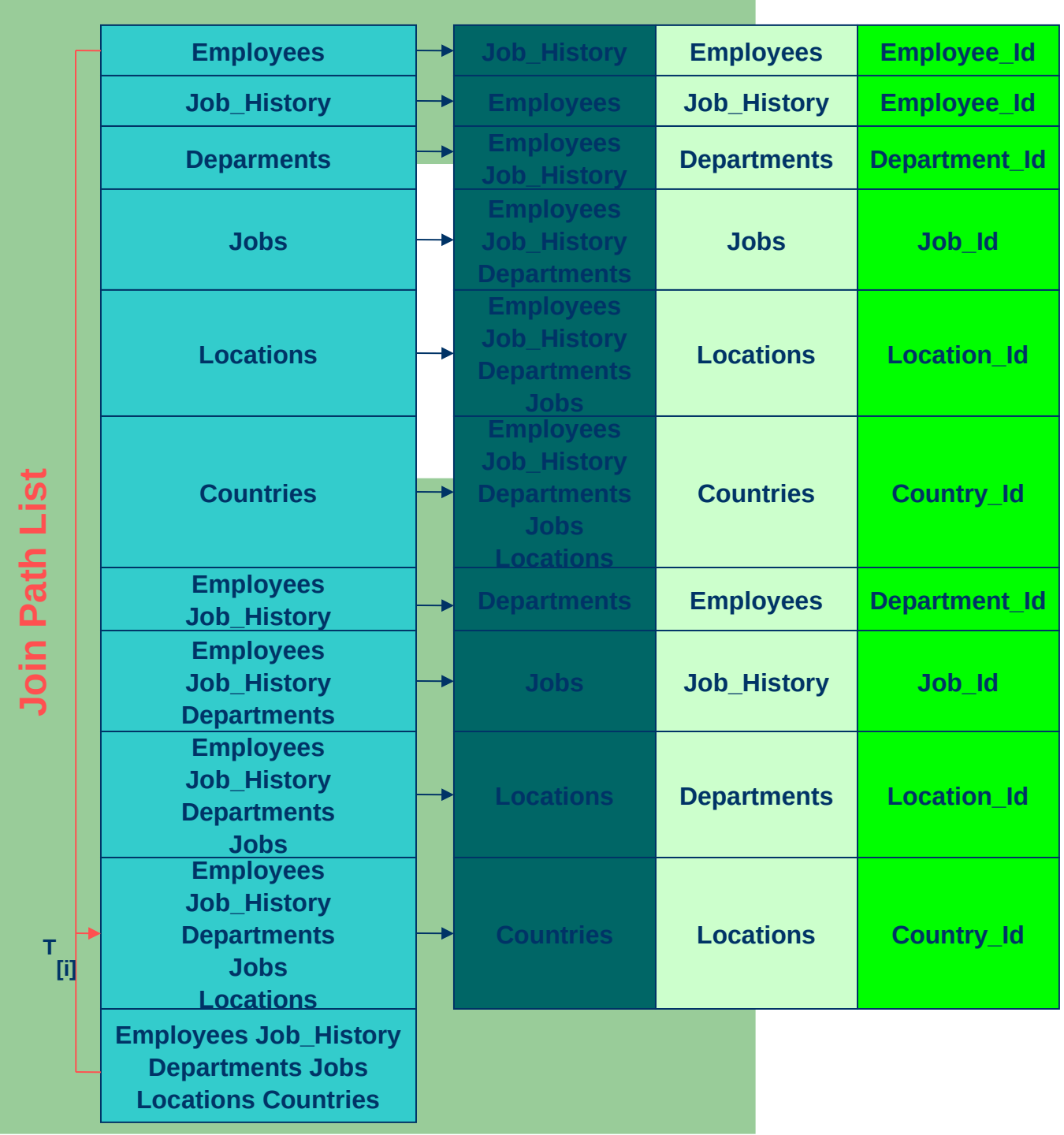
Join Path List
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Job_History
Departments
Jobs
Locations
Countries
Employee_Id
Employee_Id
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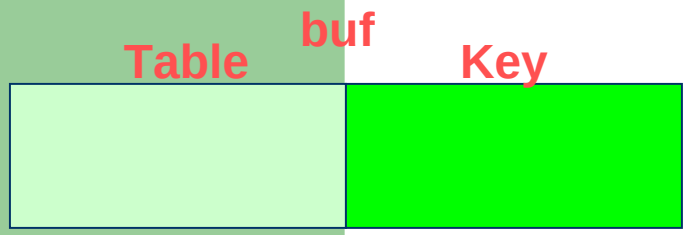

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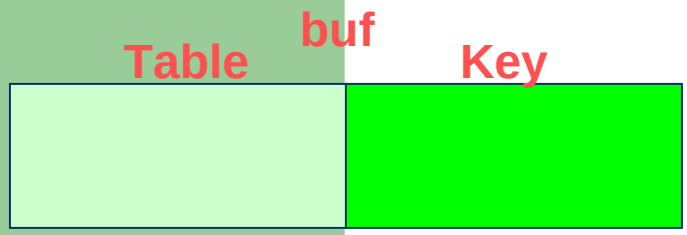

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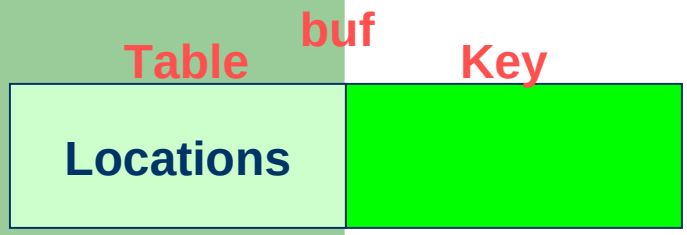

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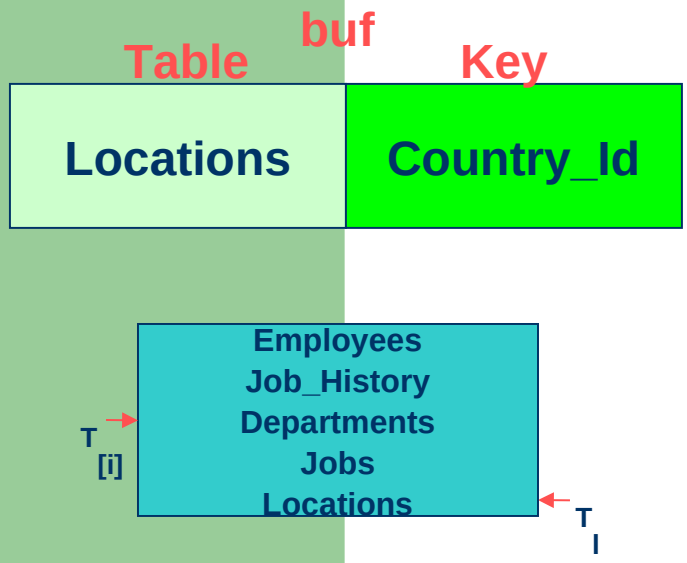

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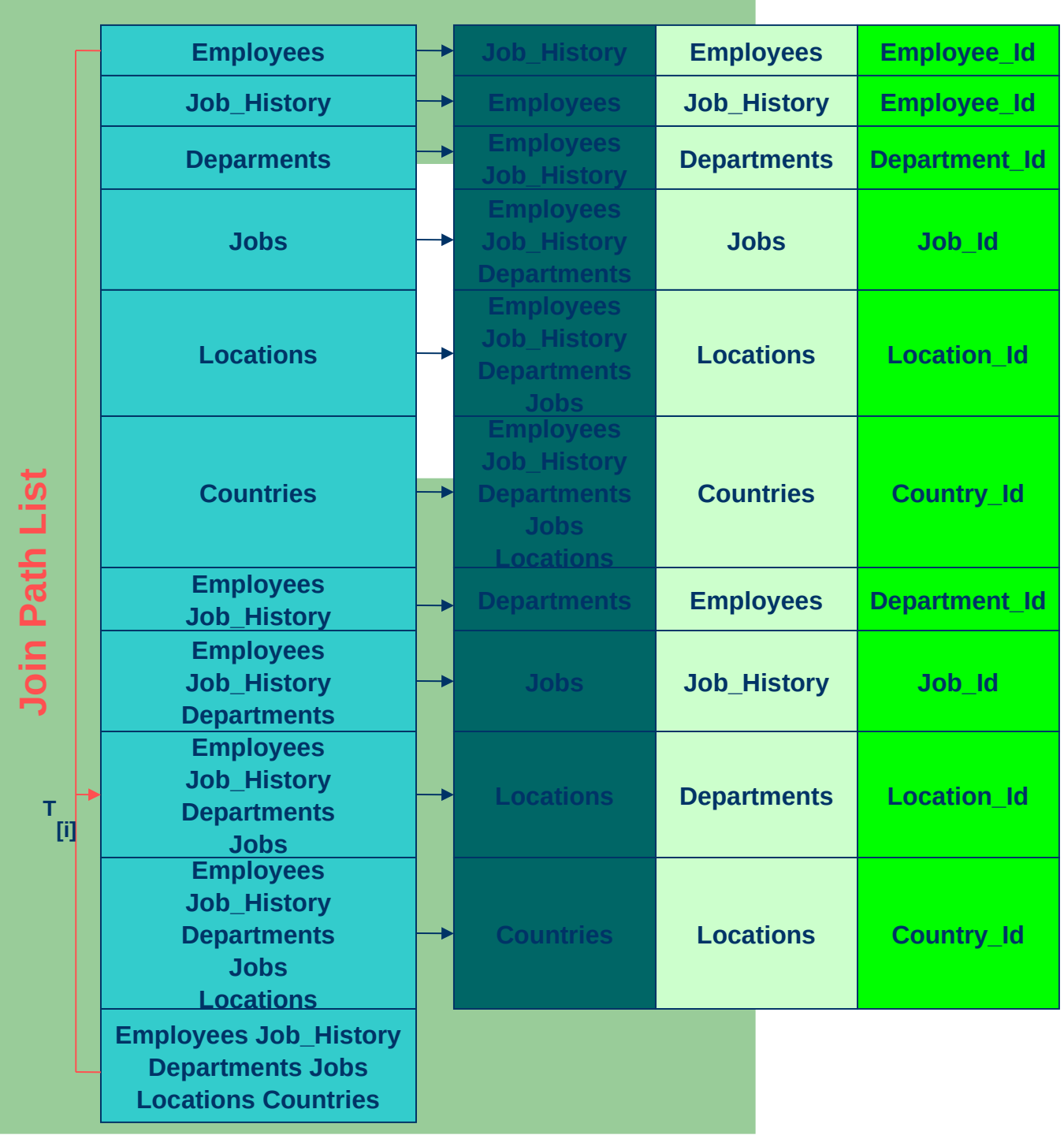
Join Path List
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Employees
Job_History
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Locations
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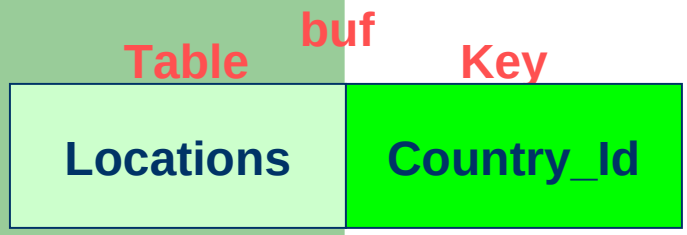

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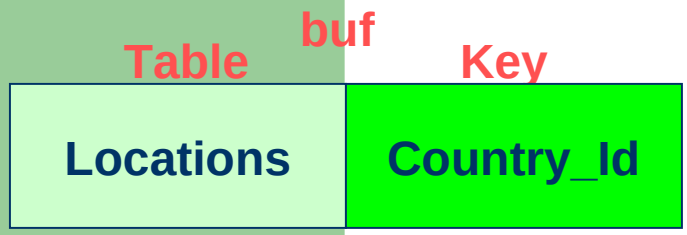

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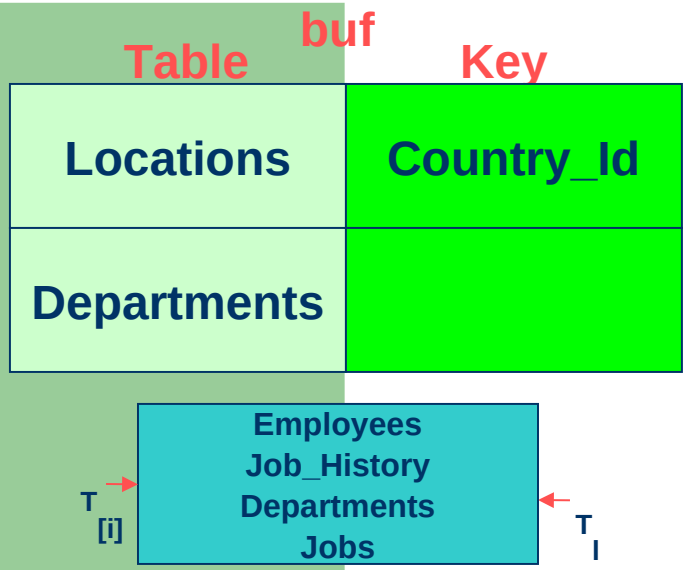

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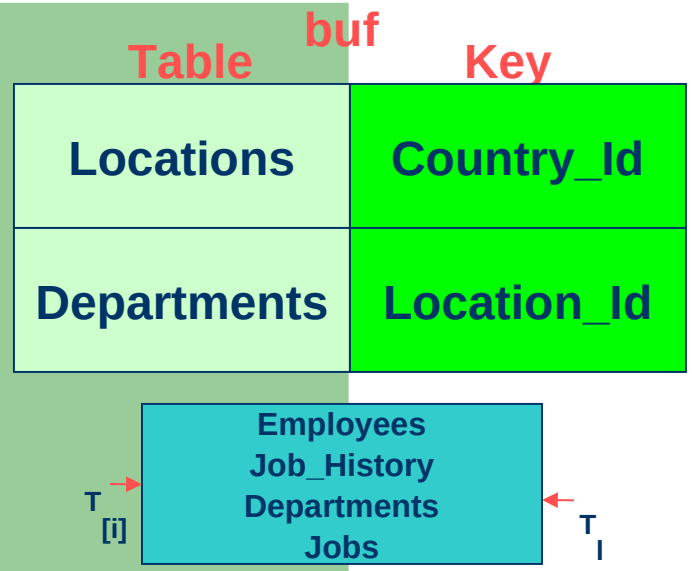

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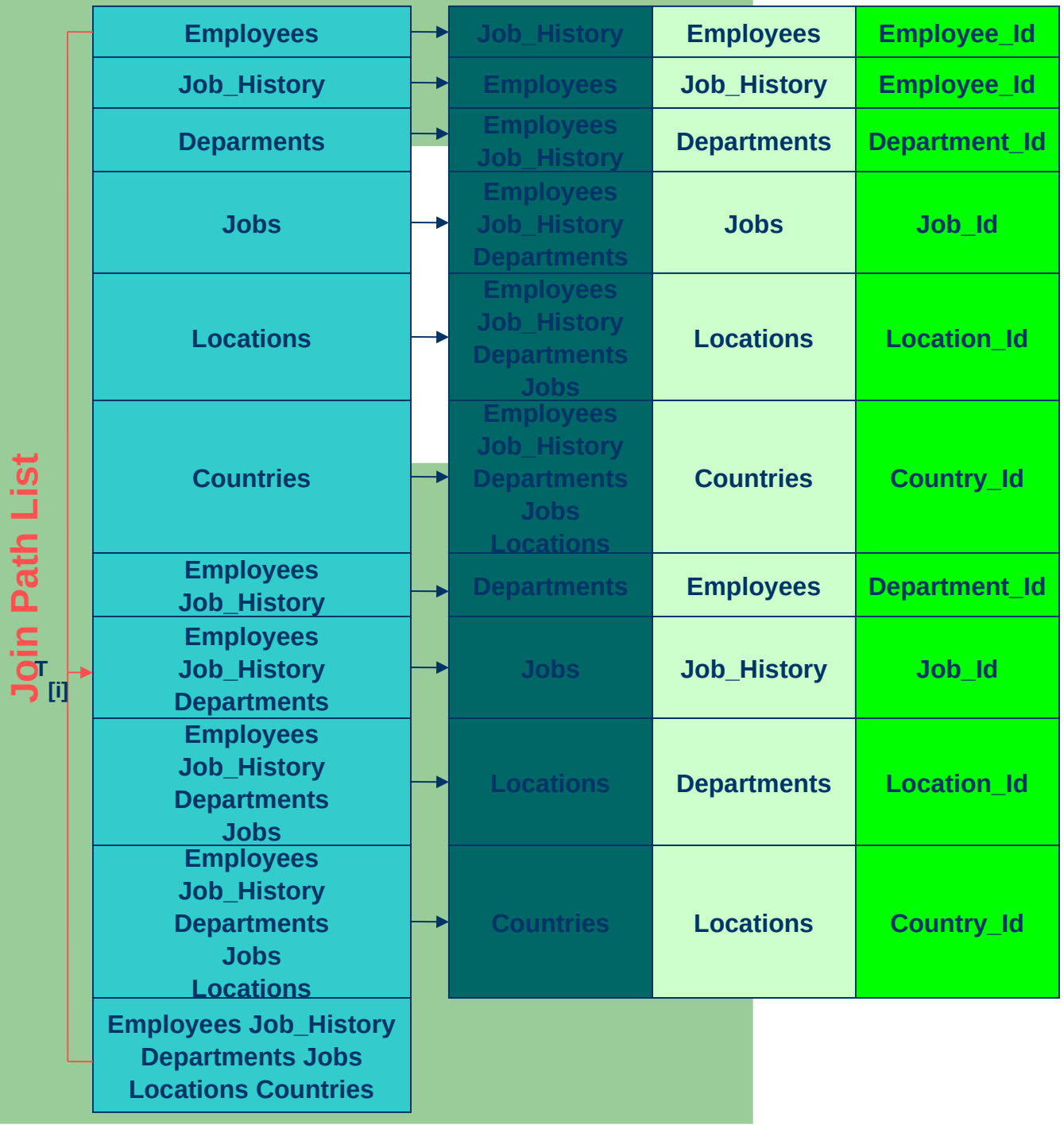
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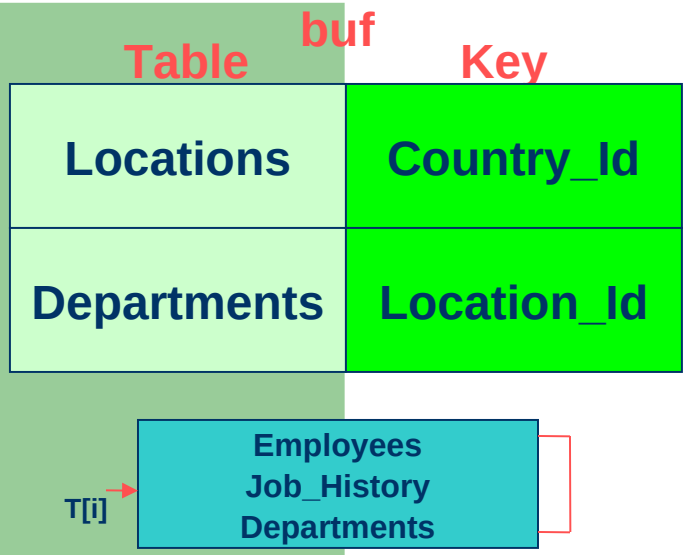

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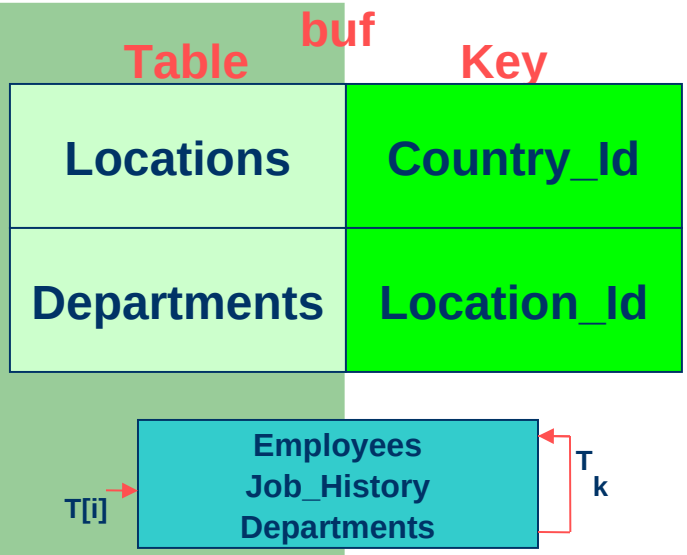

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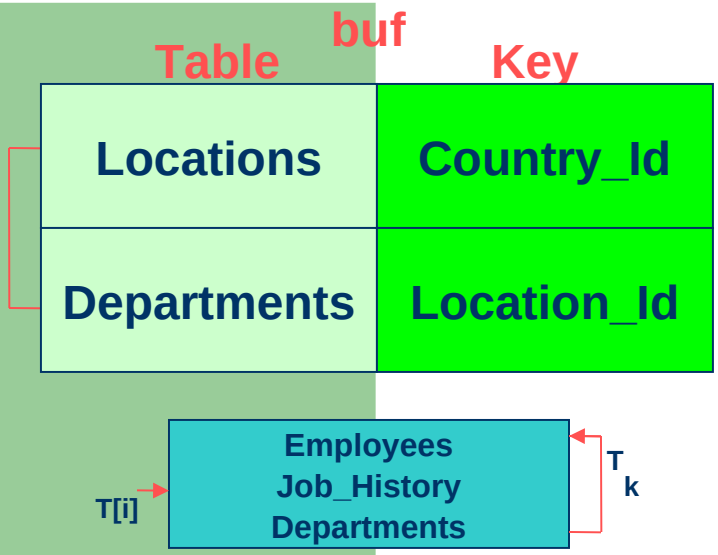

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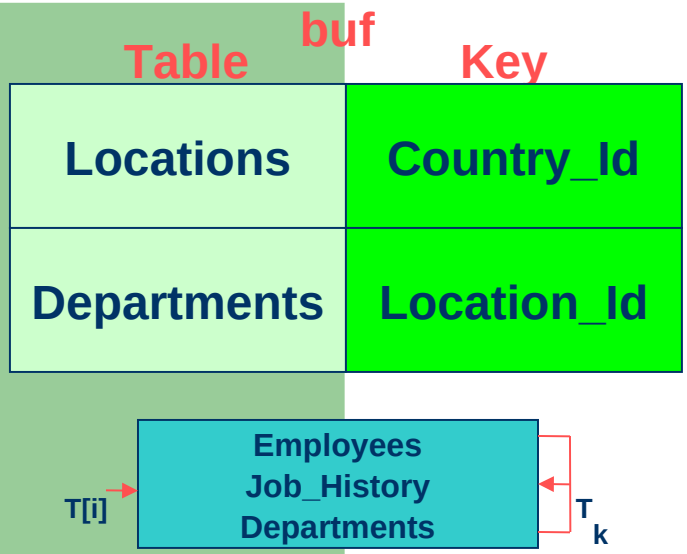

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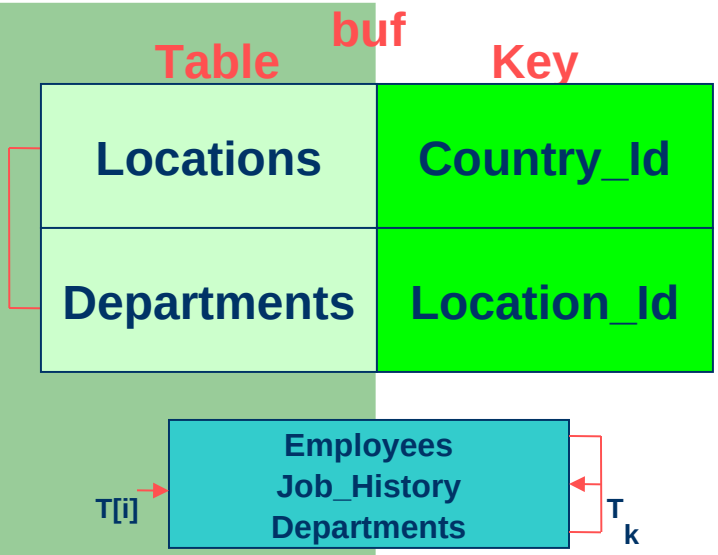

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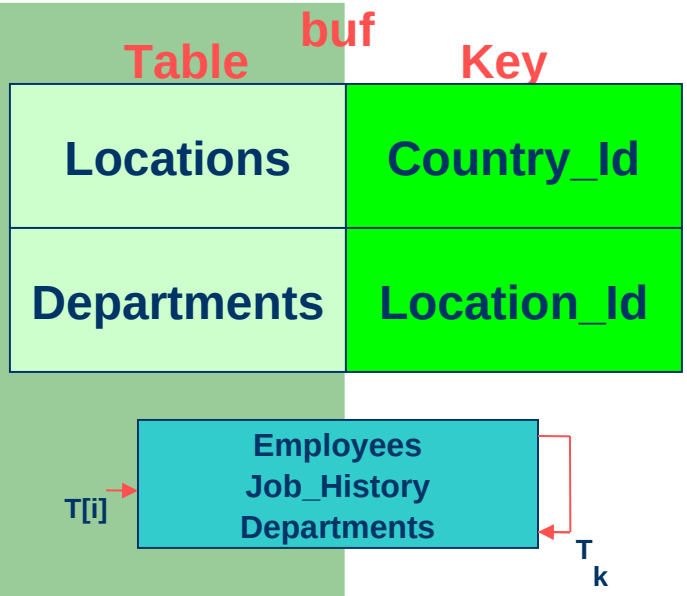

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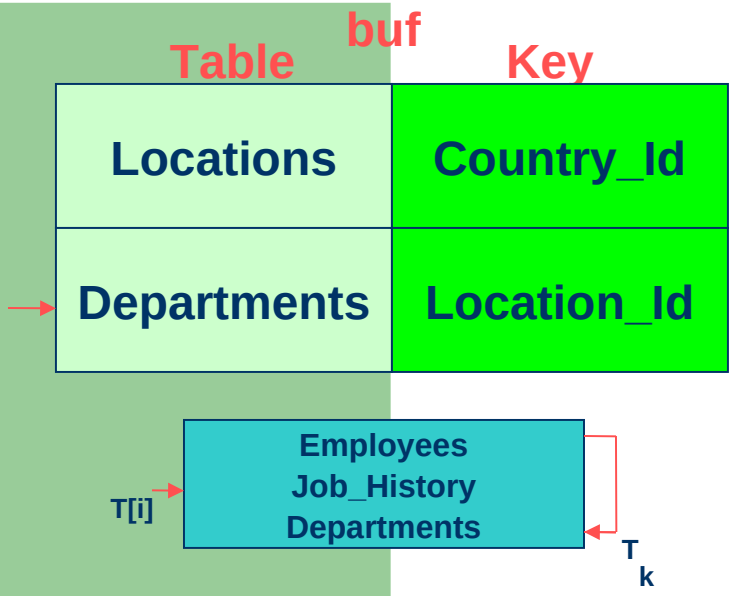

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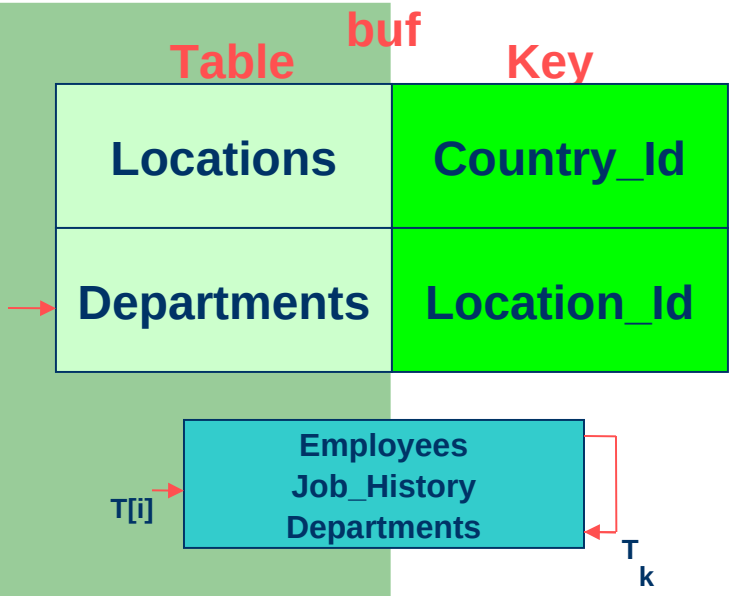

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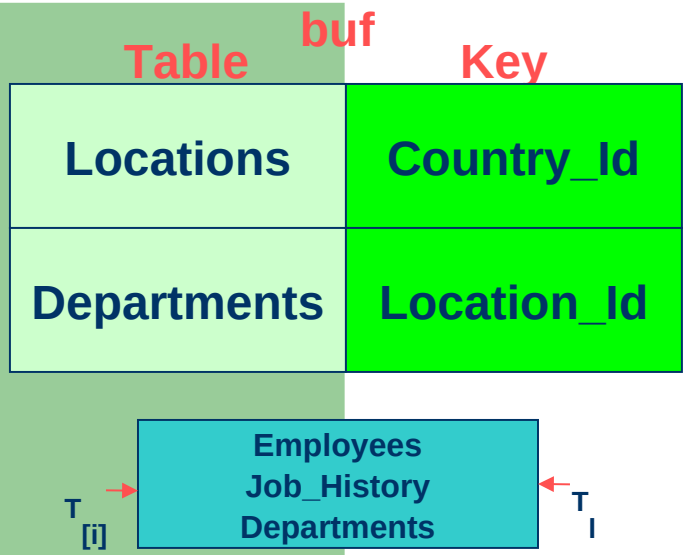

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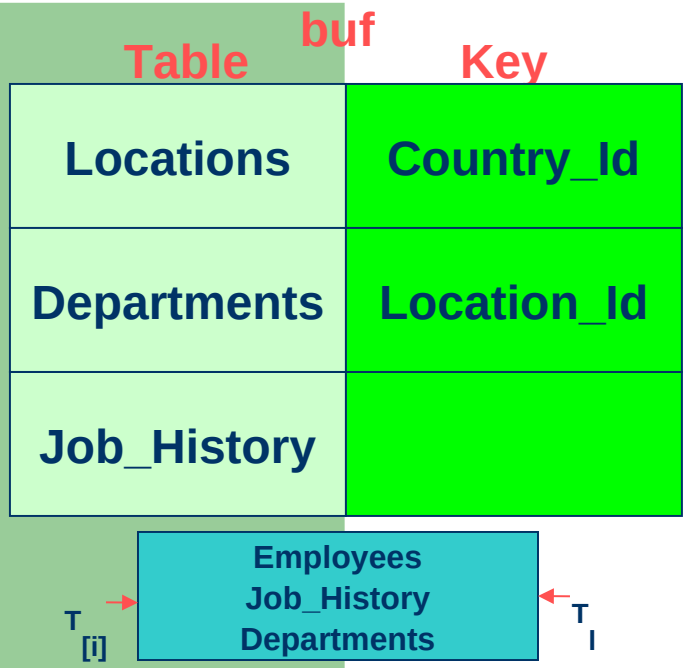

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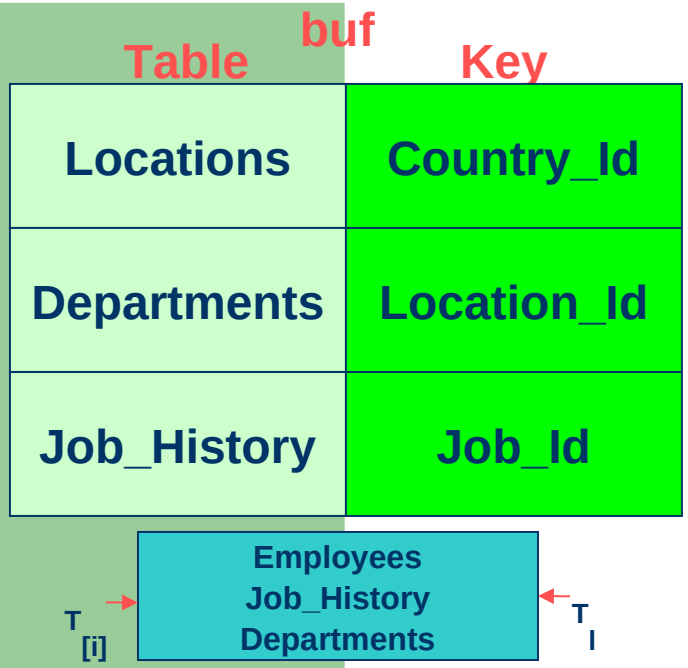

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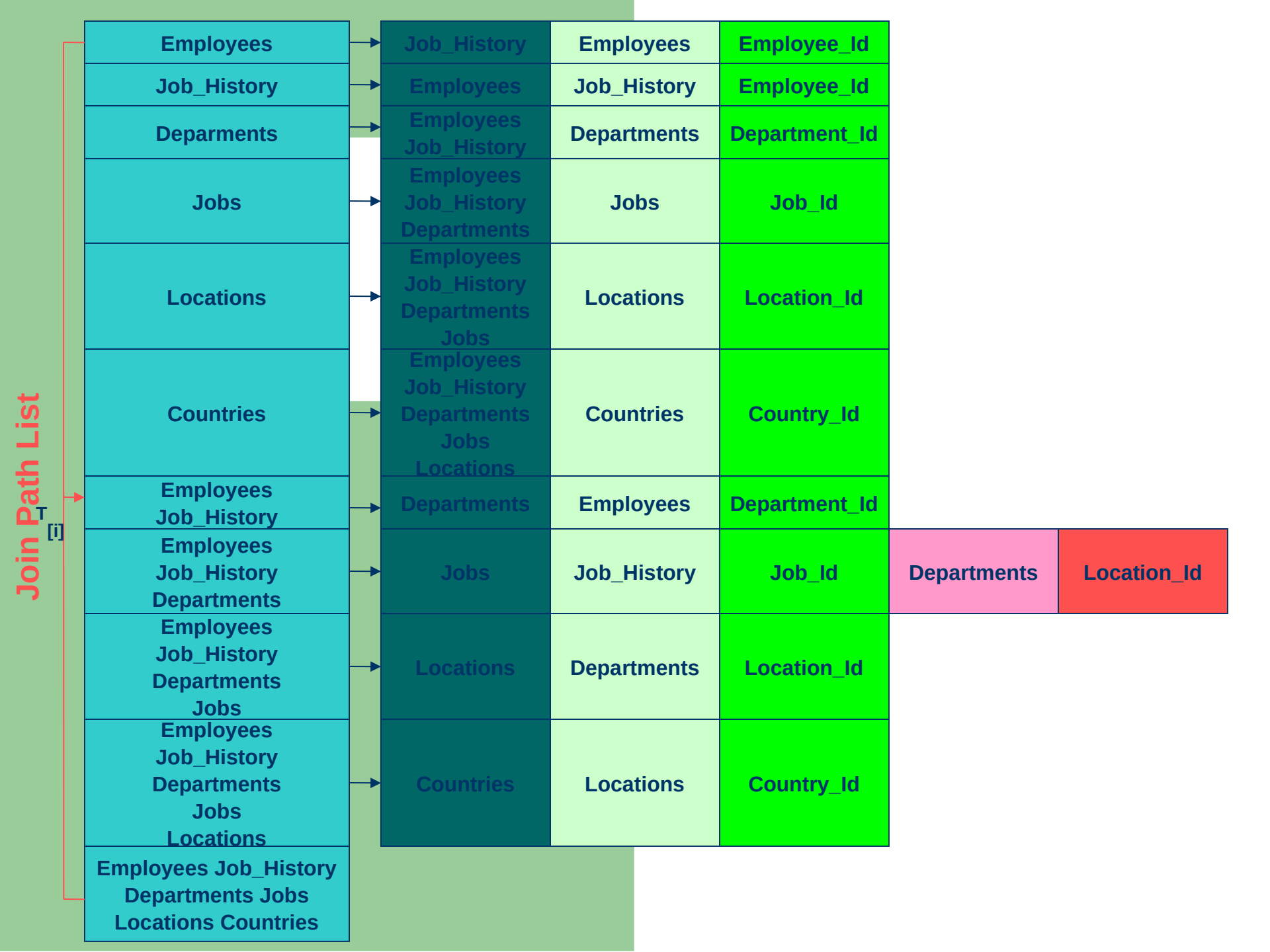
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Employees
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Employees Job_History Departments Jobs Locations
Employees
Job_History
Departments
Jobs
Locations
Countries
Employee_Id
Employee_Id
Department_Id
Job_Id
Location_Id
Country_Id
Department_Id
Job_Id
Location_Id
Country_Id
Departments
Location_Id

create a structure buf with 2 fields: Table and Key

for all the tables in JoinPathList going downward do

take one $T_{[i]}$ at a time

for all Base Tables in $T_{[i]}$ do

take one T_k at a time

for every buf.Table = T_k do

if (buf.key != Key($T_{[i]}$)) and (buf.Key not in InheritedKey($T_{[i]}$)) then InheritedKey($T_{[i]}$) += buf.key

if T_l is the table from which comes Key($T_{[i]}$) then

buf.Table = T_l

buf.key = Key($T_{[i]}$)

buf

Table	Key
Locations	Country_Id
Departments	Location_Id
Job_History	Job_Id

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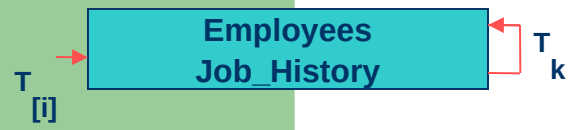
buf

Table	Key
Locations	Country_Id
Departments	Location_Id
Job_History	Job_Id



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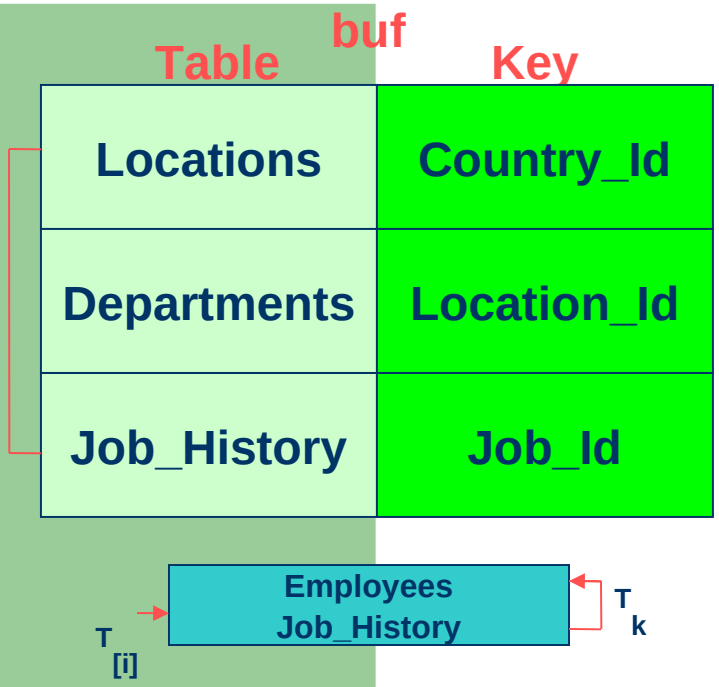

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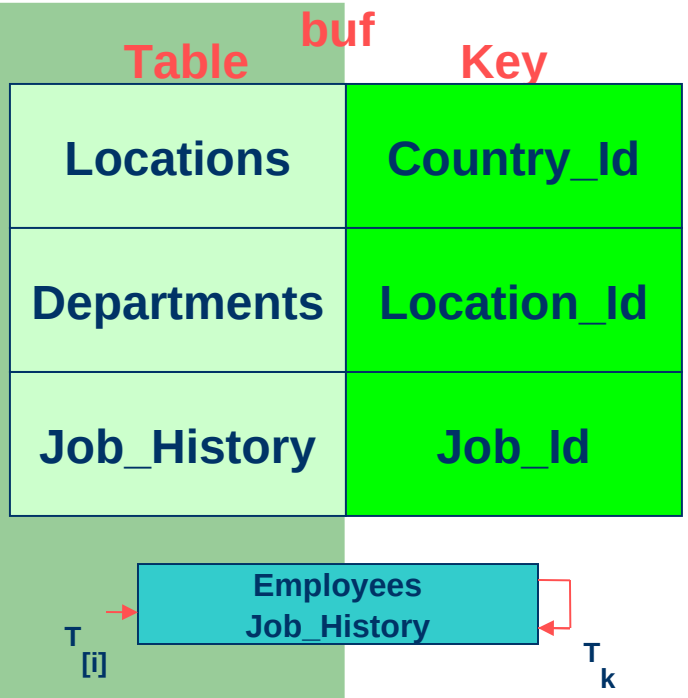

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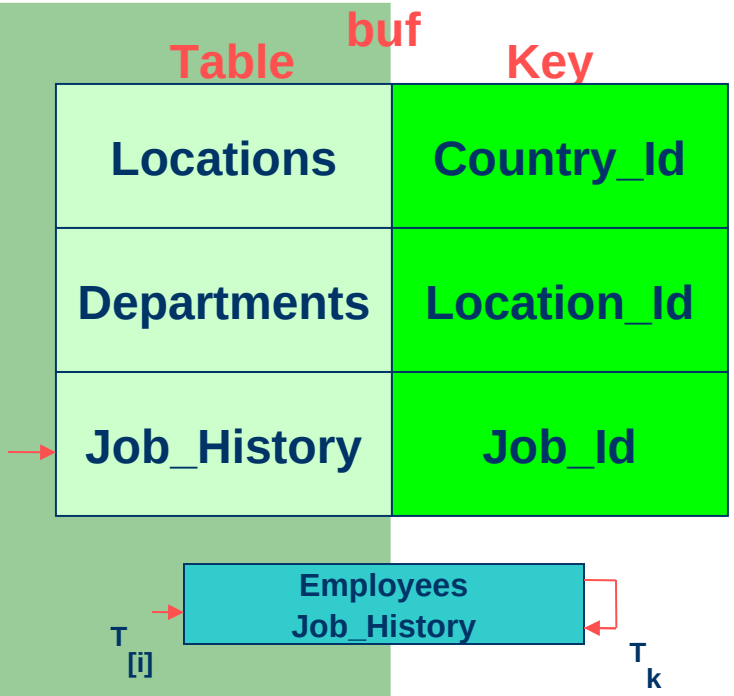

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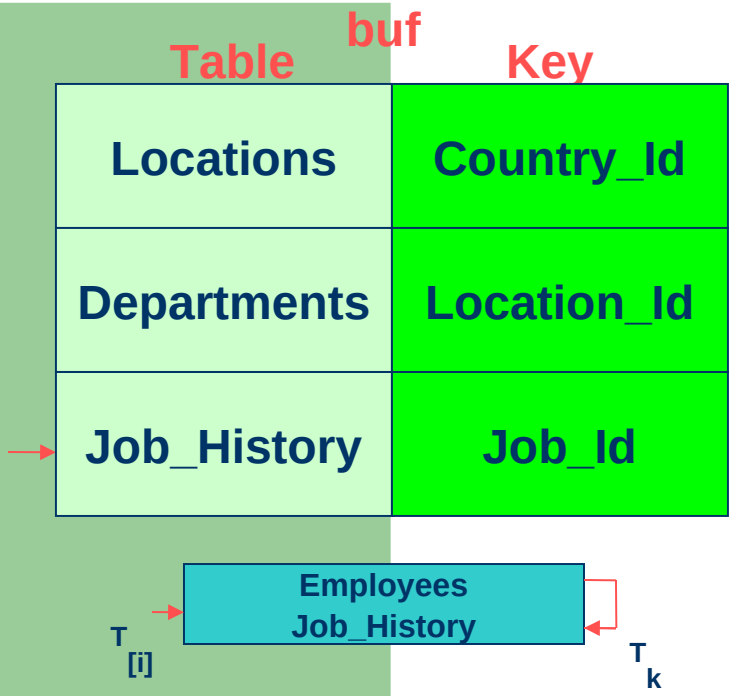

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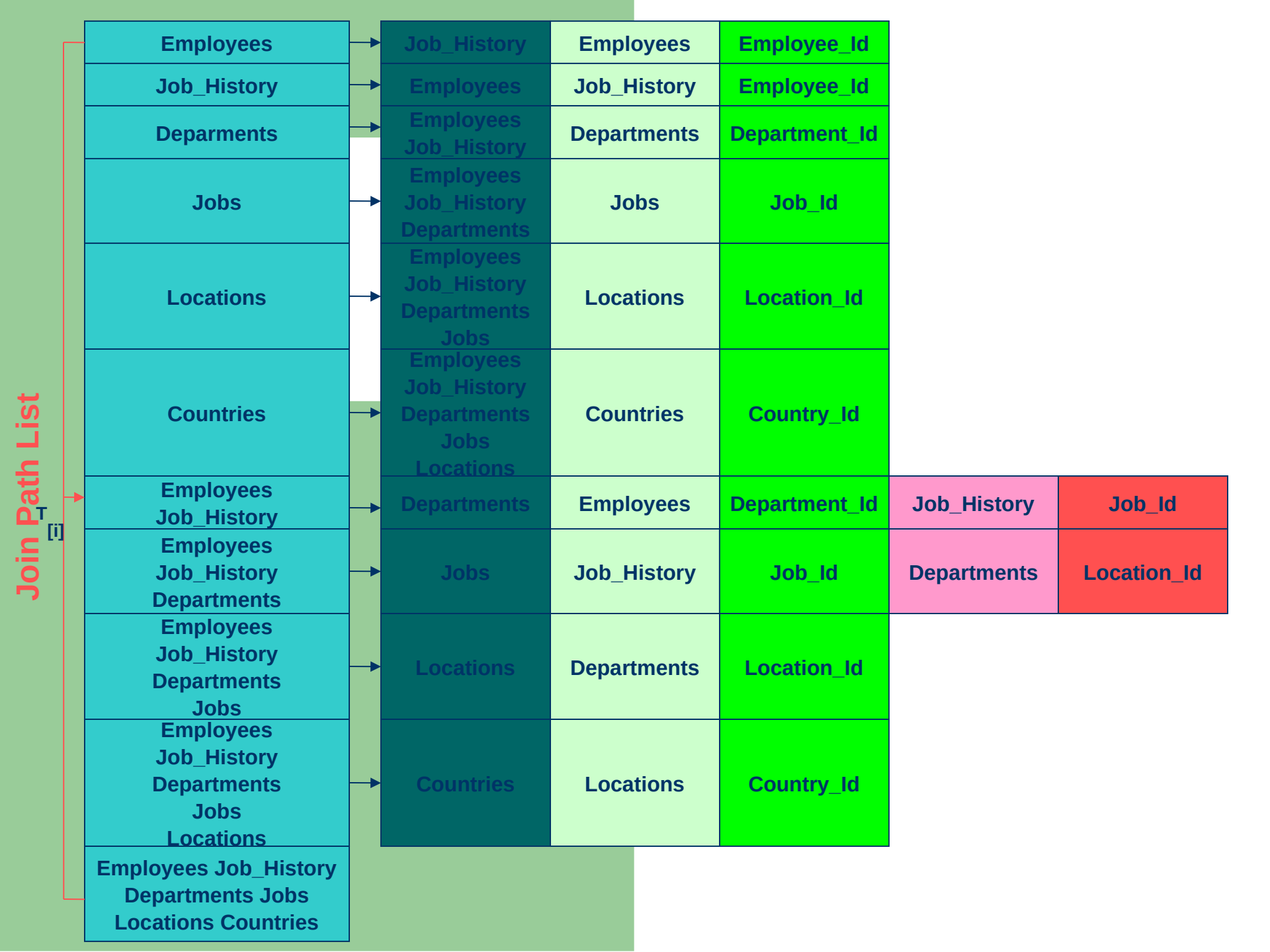
Join Path List
T[i]
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Employees Job_History Departments Jobs Locations
Employees Job_History Departments Jobs Locations Countries
Job_History
Employees
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Employees Job_History Departments Jobs Locations
Employees
Job_History
Departments
Jobs
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Countries
Employee_Id
Employee_Id
Department_Id
Job_Id
Location_Id
Country_Id
Job_History
Job_Id
Departments
Location_Id

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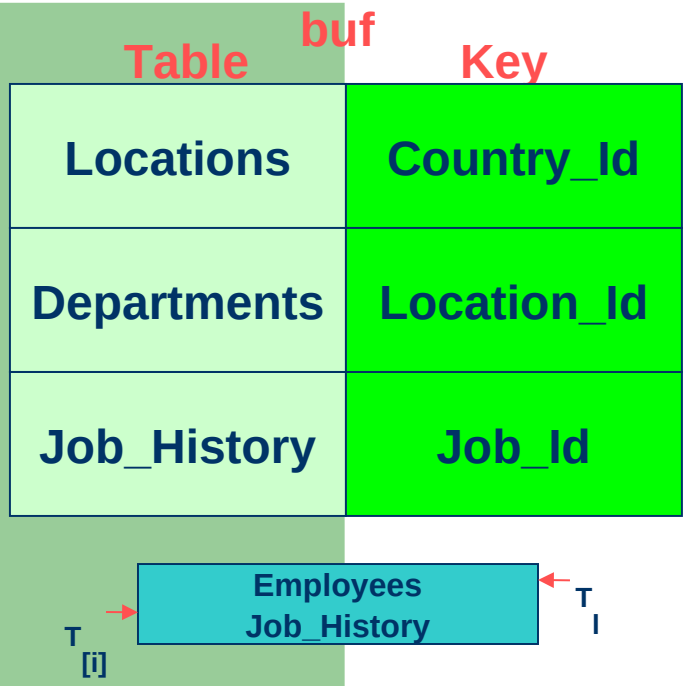

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buf.Table = T_l

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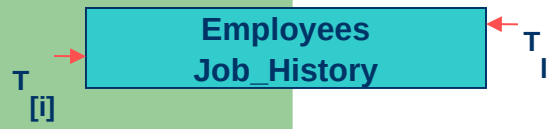
buf

Table	Key
Locations	Country_Id
Departments	Location_Id
Job_History	Job_Id
Employees	



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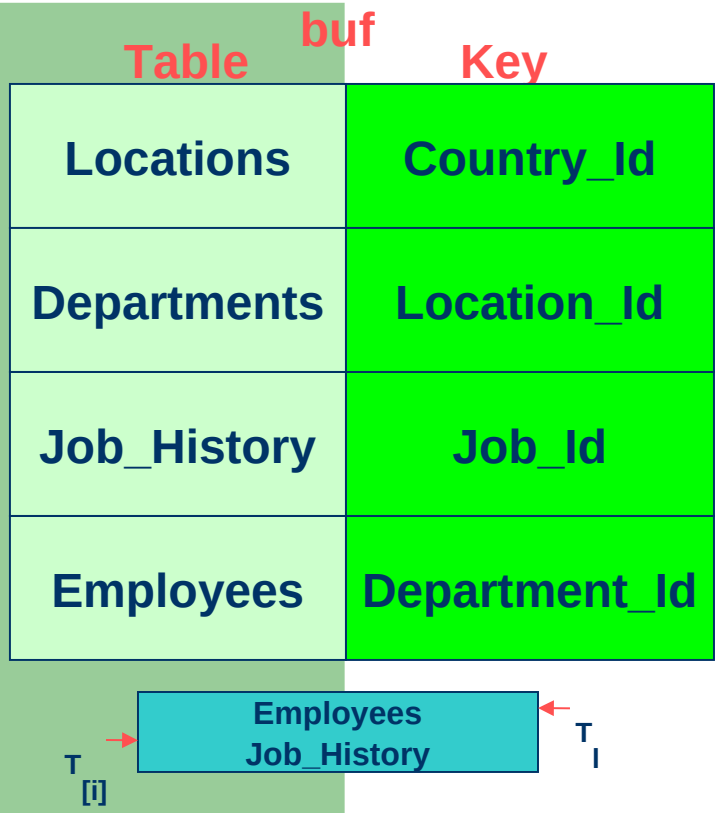

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Join Path List
T[i]
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Employees Job_History Departments Jobs Locations
Job_History
Employees
Departments
Jobs
Locations
Countries
Employees
Job_History
Departments
Jobs
Locations
Employee_Id
Employee_Id
Department_Id
Job_Id
Location_Id
Country_Id
Job_History
Job_Id
Departments
Location_Id

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buf.key = Key($T_{[i]}$)

buf

Table	Key
Locations	Country_Id
Departments	Location_Id
Job_History	Job_Id
Employees	Department_Id

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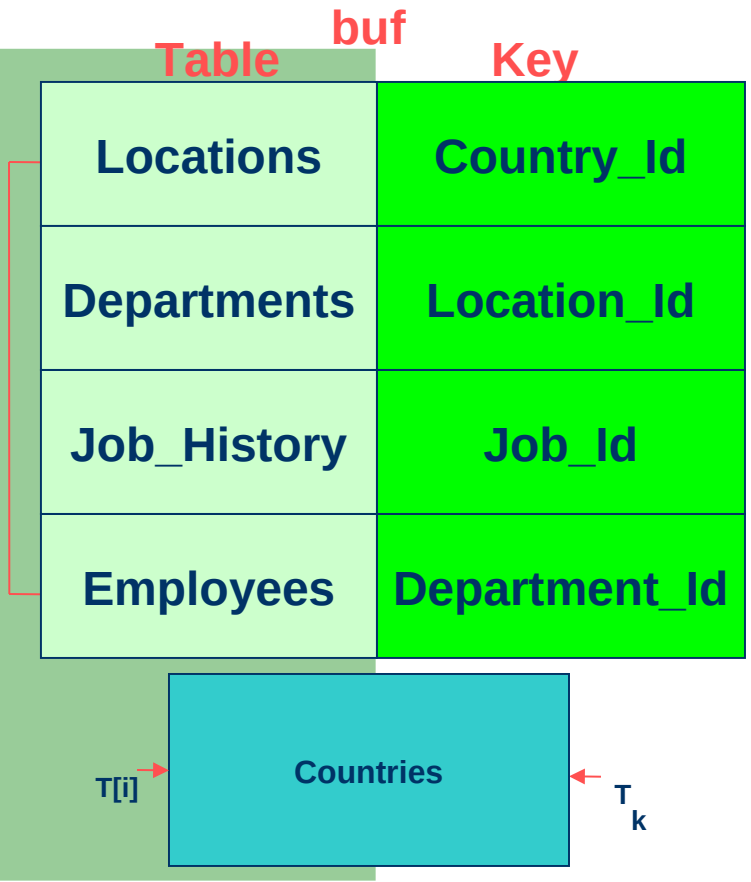

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buf.Table = T_l

buf.key = Key($T_{[i]}$)

buf

Table	Key
Locations	Country_Id
Departments	Location_Id
Job_History	Job_Id
Employees	Department_Id

T[i] → Countries

create a structure buf with 2 fields: Table and Key

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Join Path List
T [i]
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Employees Job_History Departments Jobs Locations
Employees Job_History Departments Jobs Locations Countries
Job_History
Employees
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Employees Job_History Departments Jobs Locations
Employees
Job_History
Departments
Jobs
Locations
Countries
Employee_Id
Employee_Id
Department_Id
Job_Id
Location_Id
Country_Id
Job_Id
Location_Id

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Table	Key
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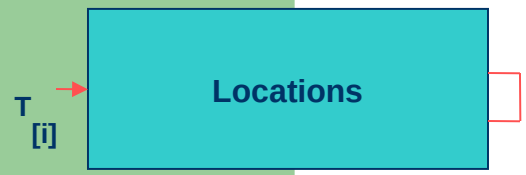
Departments	Location_Id
Job_History	Job_Id
Employees	Department_Id



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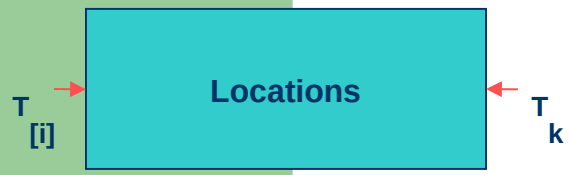

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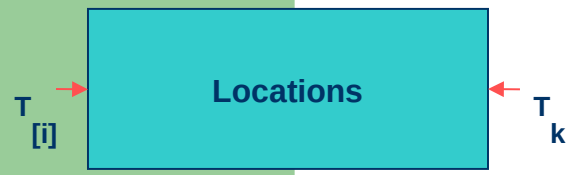

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Departments	Location_Id
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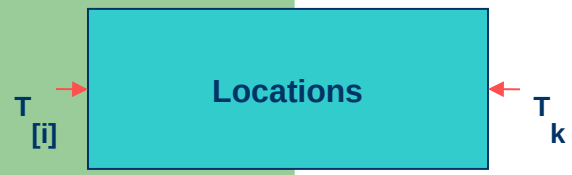

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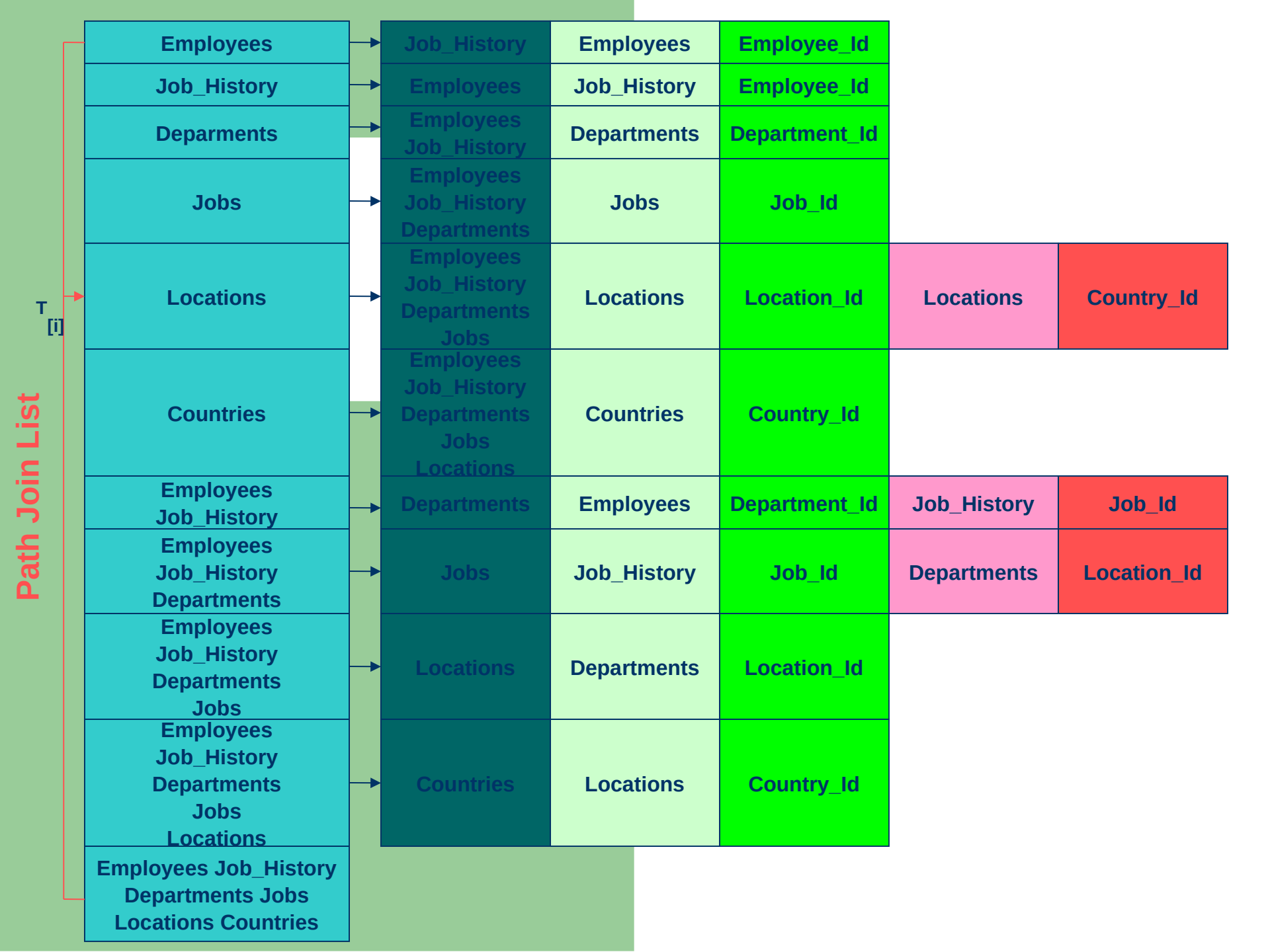
Path Join List
T [i]
Employees
Job_History
Deparments
Jobs
Locations
Countries
Employees Job_History
Employees Job_History Departments
Employees Job_History Departments Jobs
Employees Job_History Departments Jobs Locations
Job_History
Employees
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Employees Job_History Departments Jobs
Employees Job_History Departments Jobs Locations
Employees
Job_History
Departments
Jobs
Locations
Countries
Employee_Id
Employee_Id
Department_Id
Job_Id
Location_Id
Country_Id
Locations
Country_Id
Job_History
Job_Id
Departments
Location_Id

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if T_l is the table from which comes Key($T_{[i]}$) then

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buf.key = Key($T_{[i]}$)

buf

Table	Key
Locations	Country_Id
Departments	Location_Id
Job_History	Job_Id
Employees	Department_Id

$T_{[i]}$ → Locations

create a structure buf with 2 fields: Table and Key

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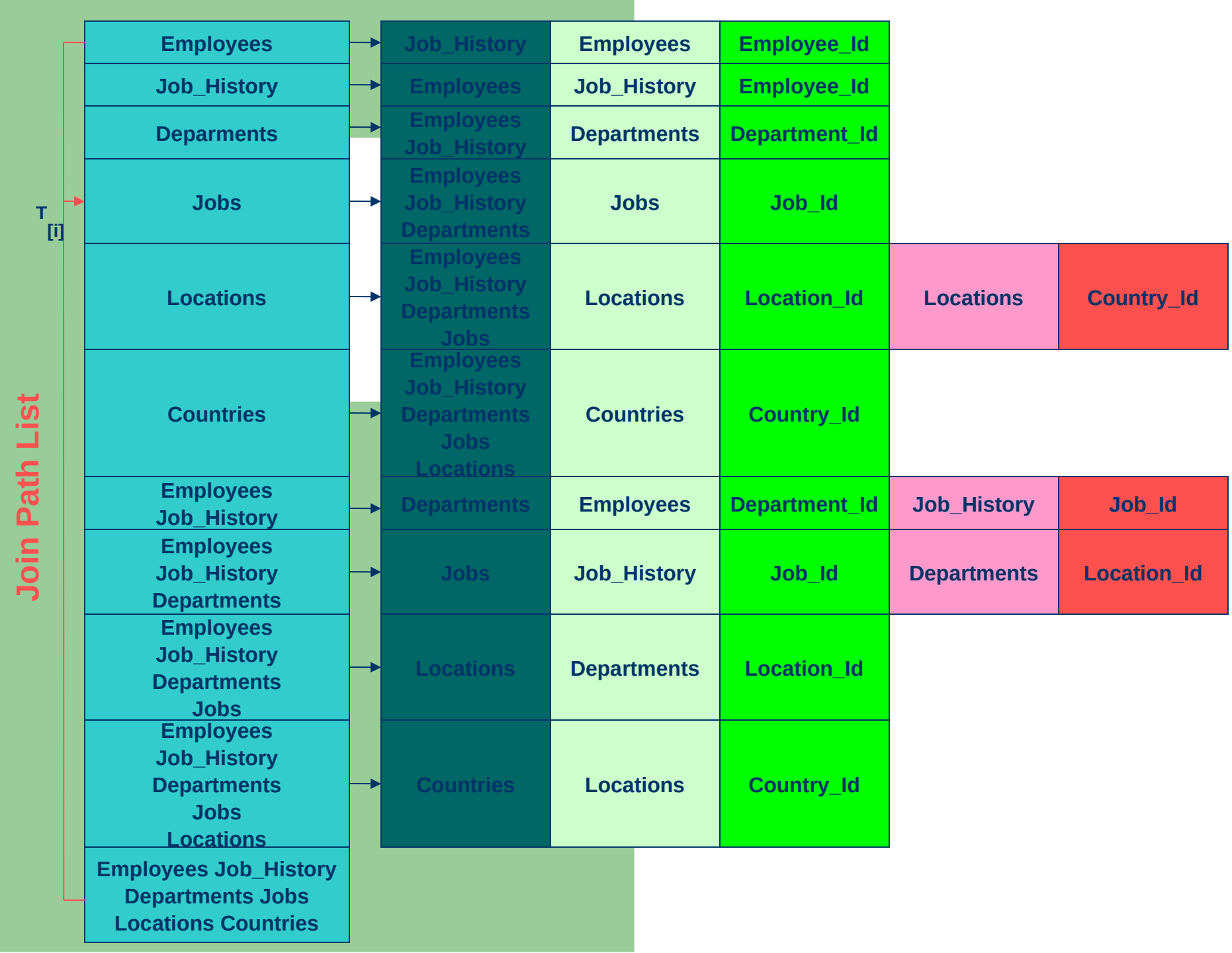
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Job_History
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Employees
Job_History
Departments
Jobs
Locations
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Employee_Id
Department_Id
Job_Id
Location_Id
Country_Id
Locations
Country_Id
Job_History
Job_Id
Departments
Location_Id

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Locations	Country_Id
Departments	Location_Id
Job_History	Job_Id
Employees	Department_Id

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take one T_k at a time

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if (buf.key != Key($T_{[i]}$)) and (buf.Key not in InheritedKey($T_{[i]}$)) then InheritedKey($T_{[i]}$) += buf.key

if T_l is the table from which comes Key($T_{[i]}$) then

buf.Table = T_l

buf.key = Key($T_{[i]}$)

buf

Table	Key
Locations	Country_Id
Departments	Location_Id
Job_History	Job_Id
Employees	Department_Id

create a structure buf with 2 fields: Table and Key

for all the tables in JoinPathList going downward do

take one $T_{[i]}$ at a time

for all Base Tables in $T_{[i]}$ do

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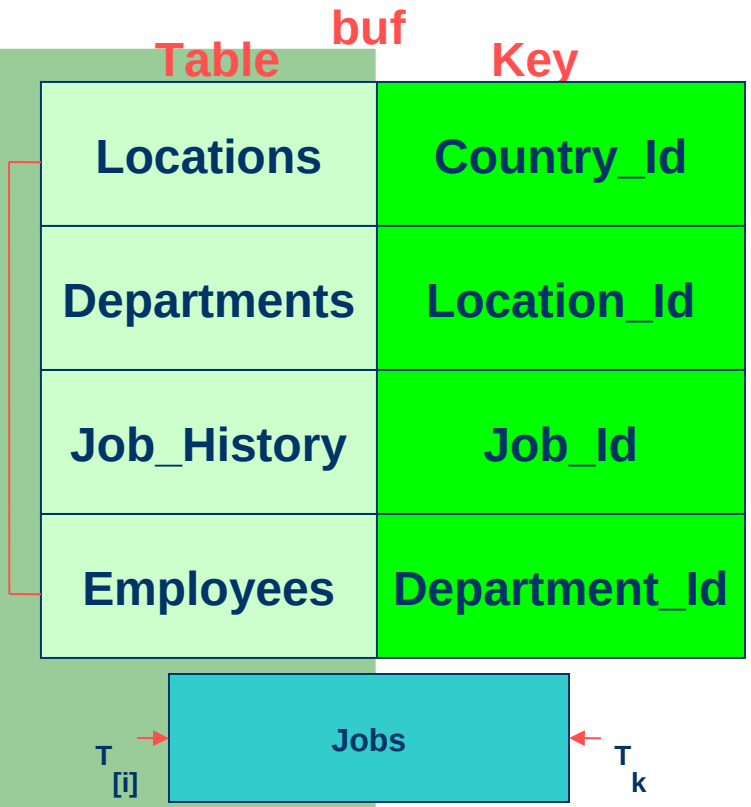

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Locations	Country_Id
Departments	Location_Id
Job_History	Job_Id
Employees	Department_Id

$T_{[i]}$ → Jobs

create a structure buf with 2 fields: Table and Key

for all the tables in JoinPathList going downward do

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for all Base Tables in $T_{[i]}$ do

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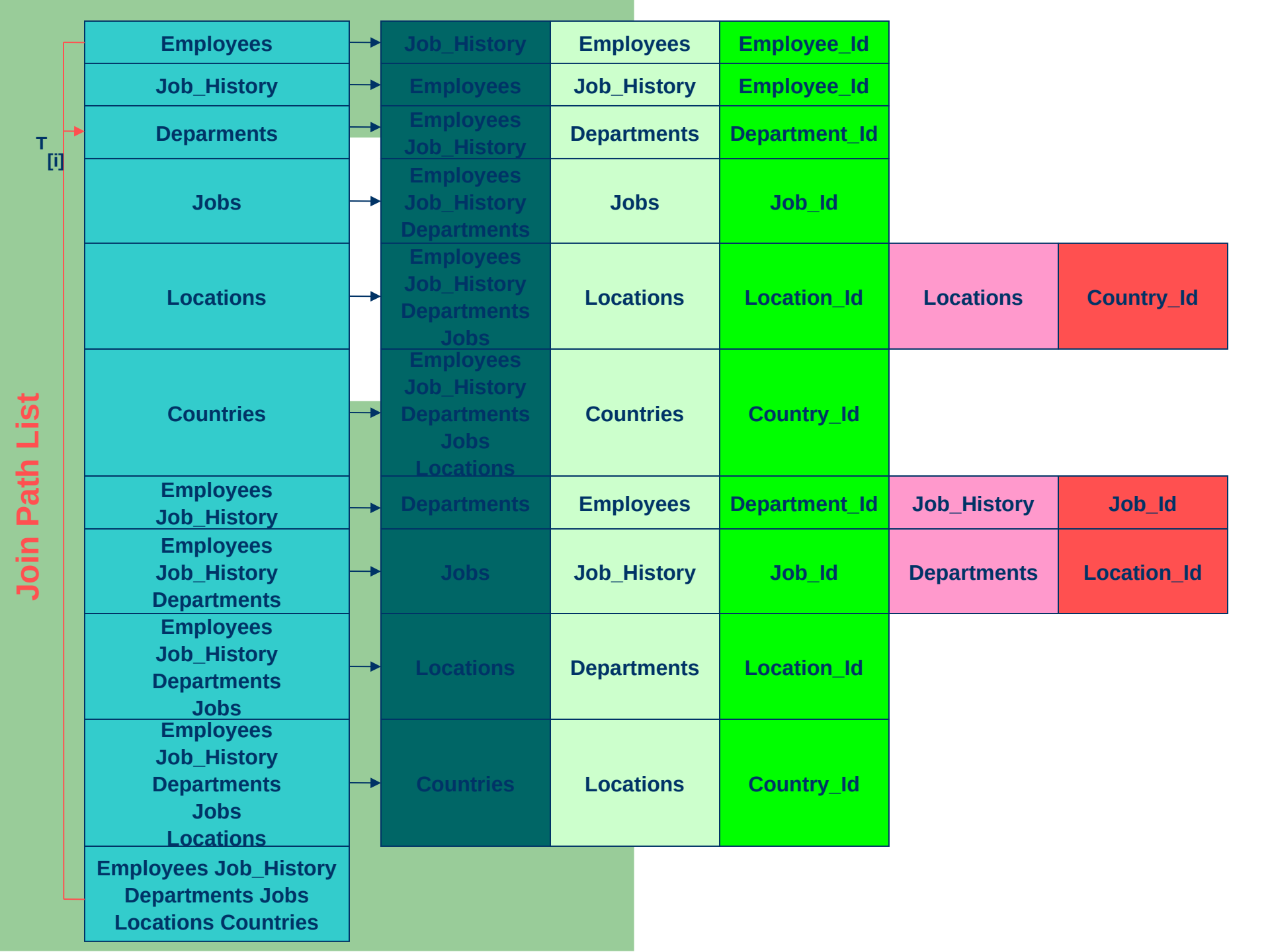
Join Path List
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Countries
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Departments
Location_Id

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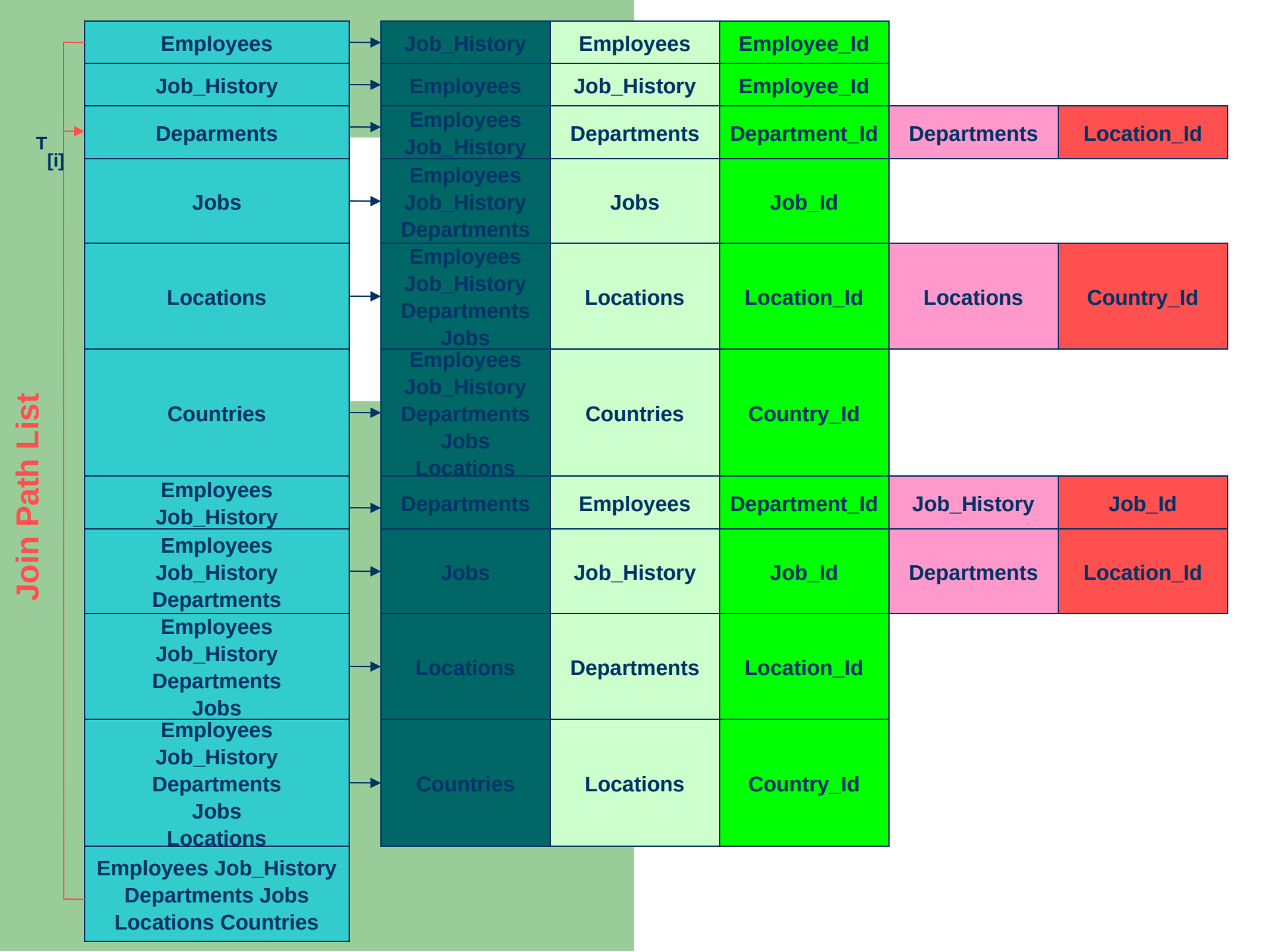
Join Path List
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Job_History
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Location_Id

create a structure buf with 2 fields: Table and Key

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buf

Table	Key
Locations	Country_Id
Departments	Location_Id
Job_History	Job_Id
Employees	Department_Id

$T_{[i]}$ → Deparments

create a structure buf with 2 fields: Table and Key

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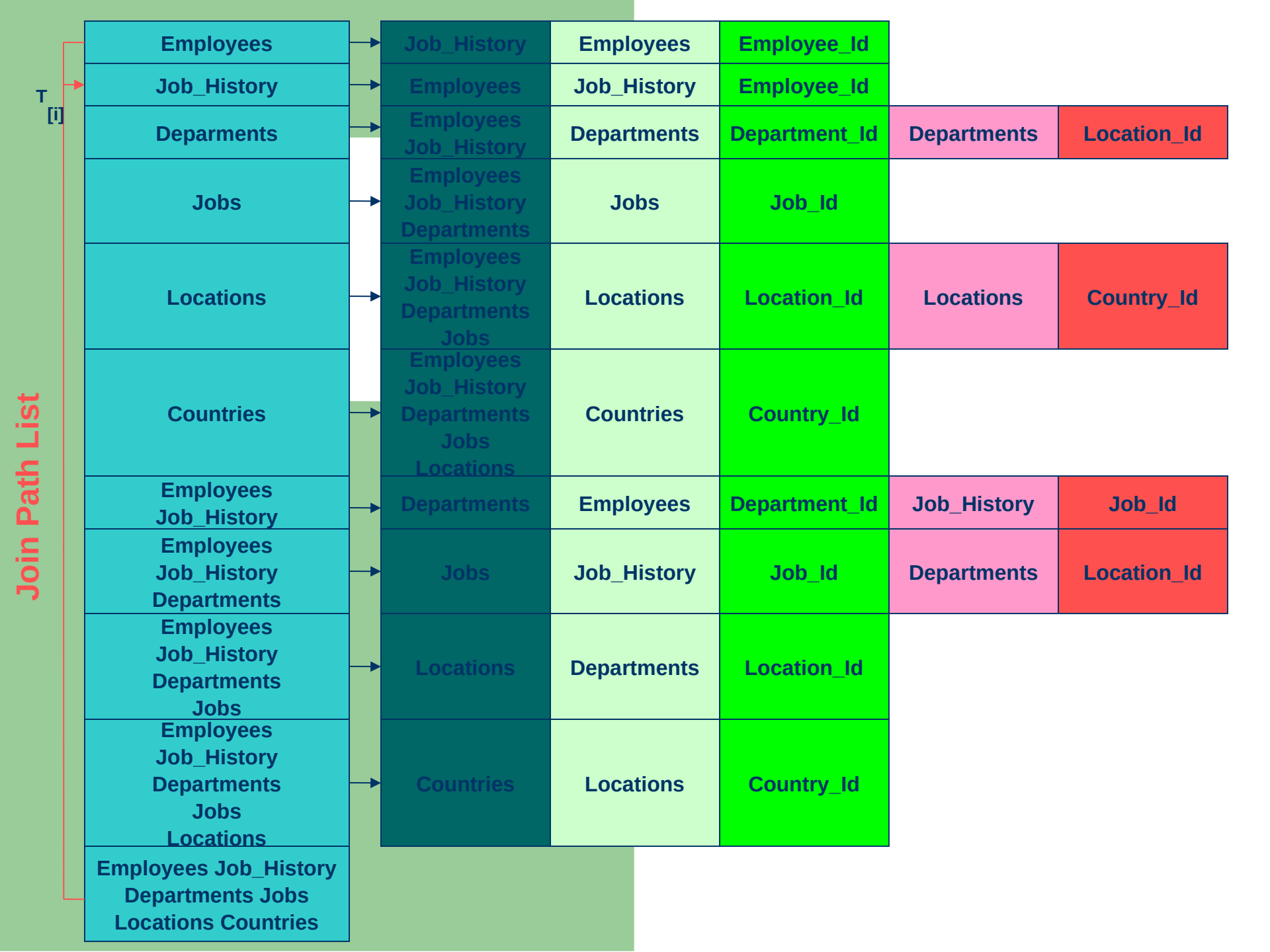
Join Path List
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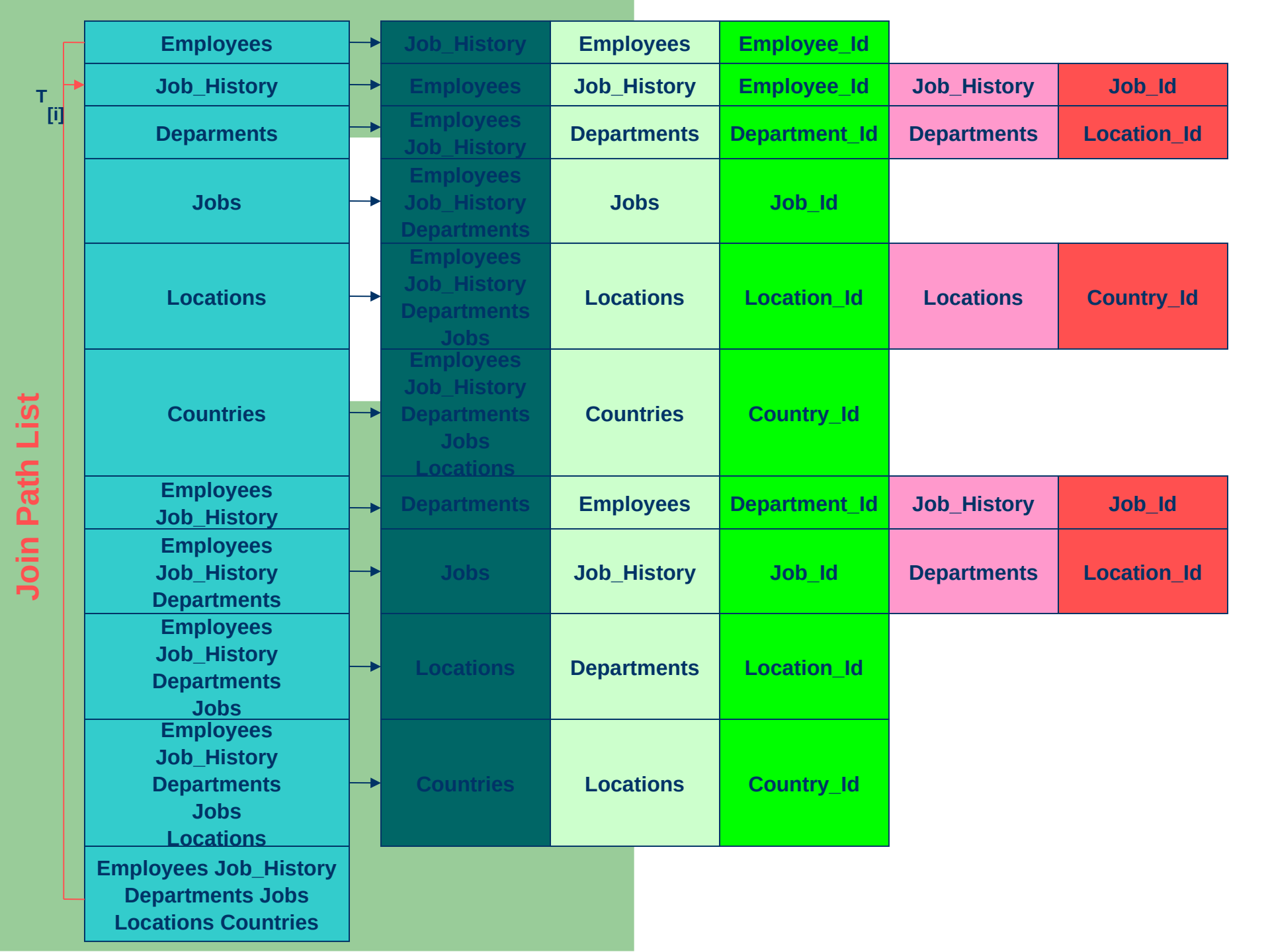
Join Path List
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Job_History
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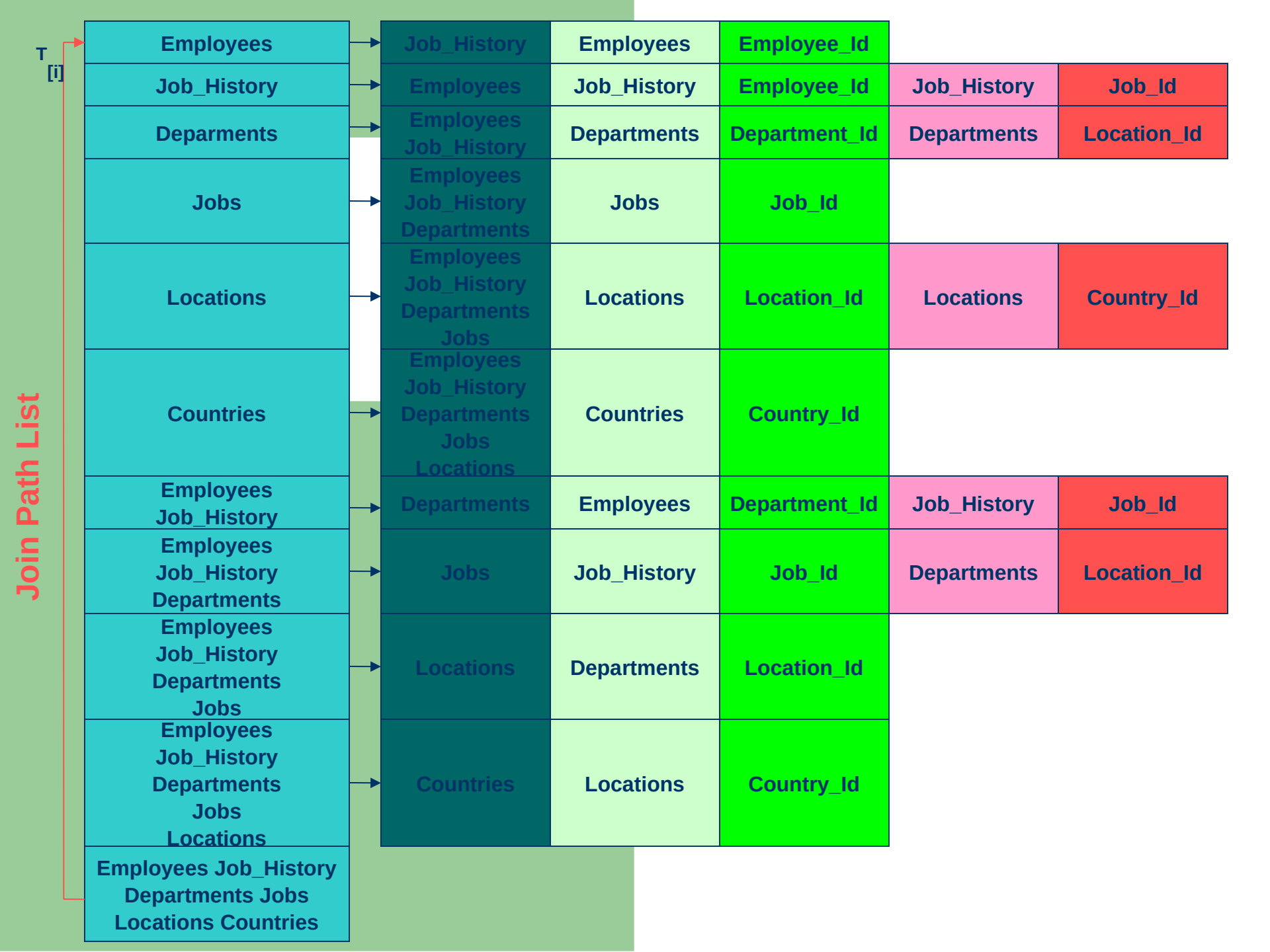
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Deparments
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Job_History
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Job_Id
Location_Id
Country_Id
Job_History
Job_Id
Departments
Location_Id

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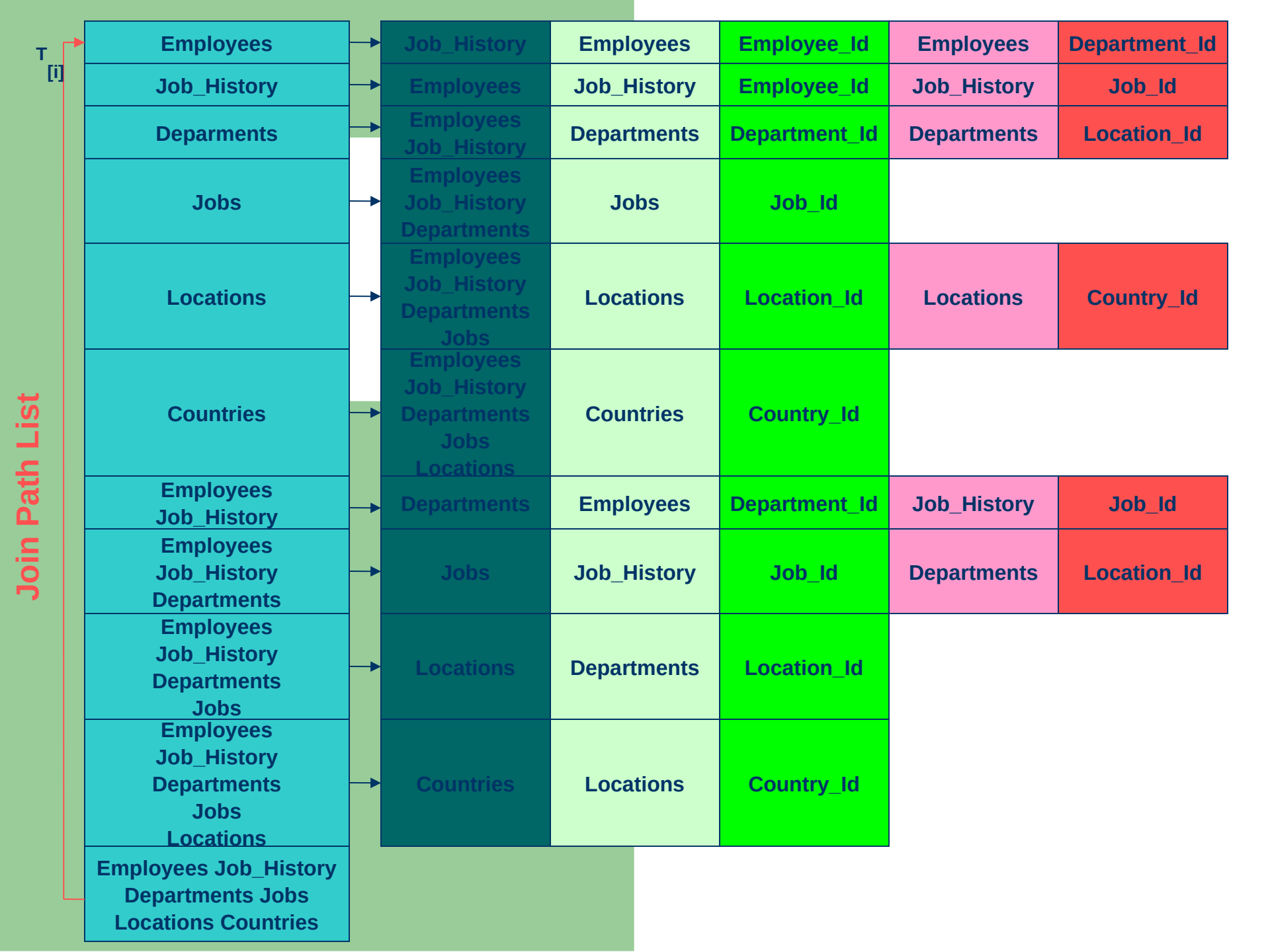
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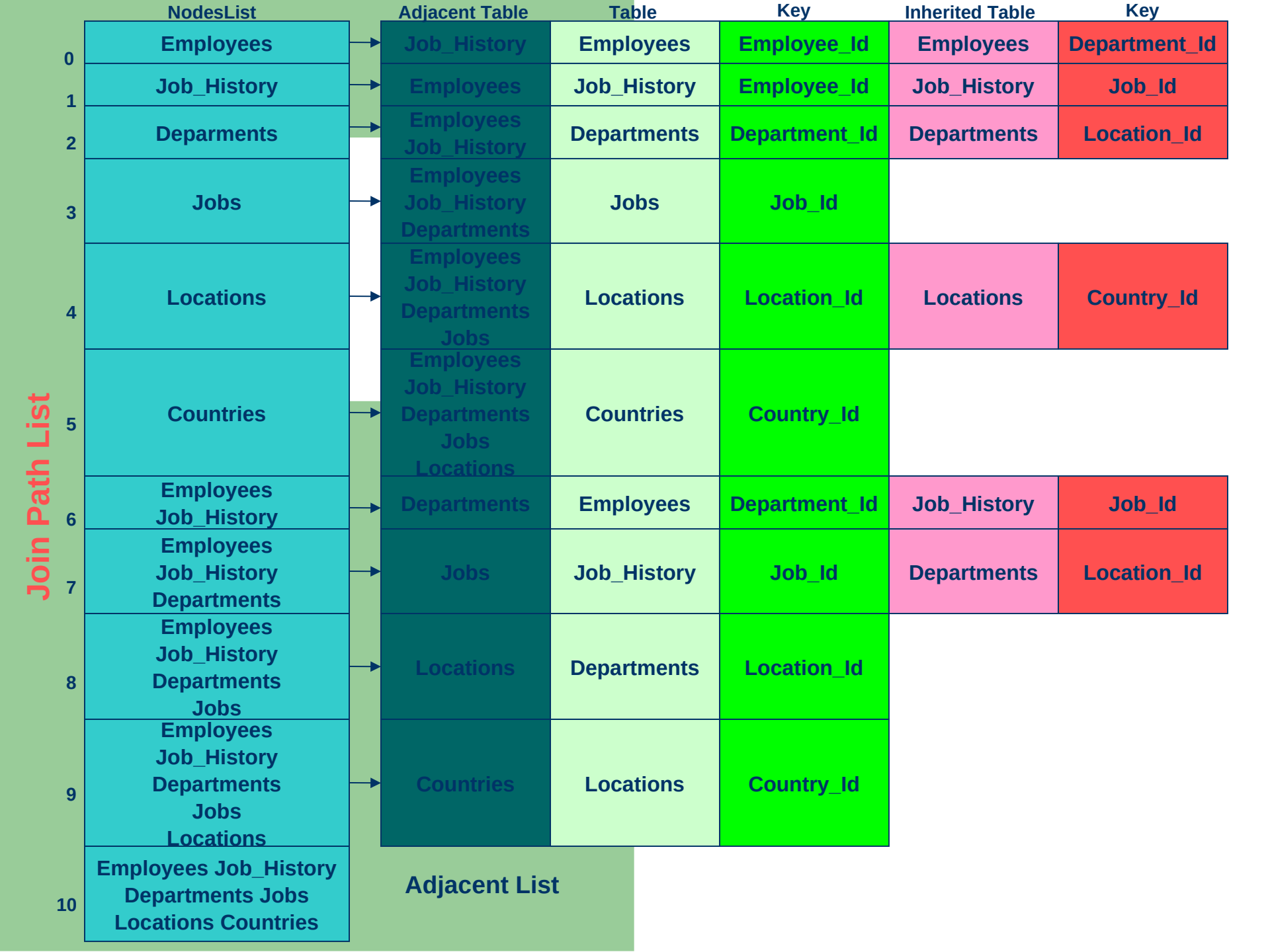
Join Path List
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Inherited Table
Key
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Employees
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Department_Id
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Location_Id
9
Employees
Job_History
Departments
Jobs
Locations
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Locations
Country_Id
10
Employees Job_History
Departments Jobs
Locations Countries
Adjacent List

Give a general name for the B⋈Tree.

Give for every entry in the JoinPathList a B+Tree index with name as the B⋈Tree + the PathJoinList entry number.

About the last virtual table, it index has no keys, it works because we consider pairs of < keys, Data Pointers > so they are ordered by their data pointers. Scanning the index we get all the sequences of joined data pointers.

Non Terminal has repeated empty keys they point to different pages. When comes a key it would be inserted in the last page.

Duplicate keys are inserted and when a page is full , the key is repeated in the non terminal.

In any case we can incorporate any key of our choice from the tables forming the virtual table.

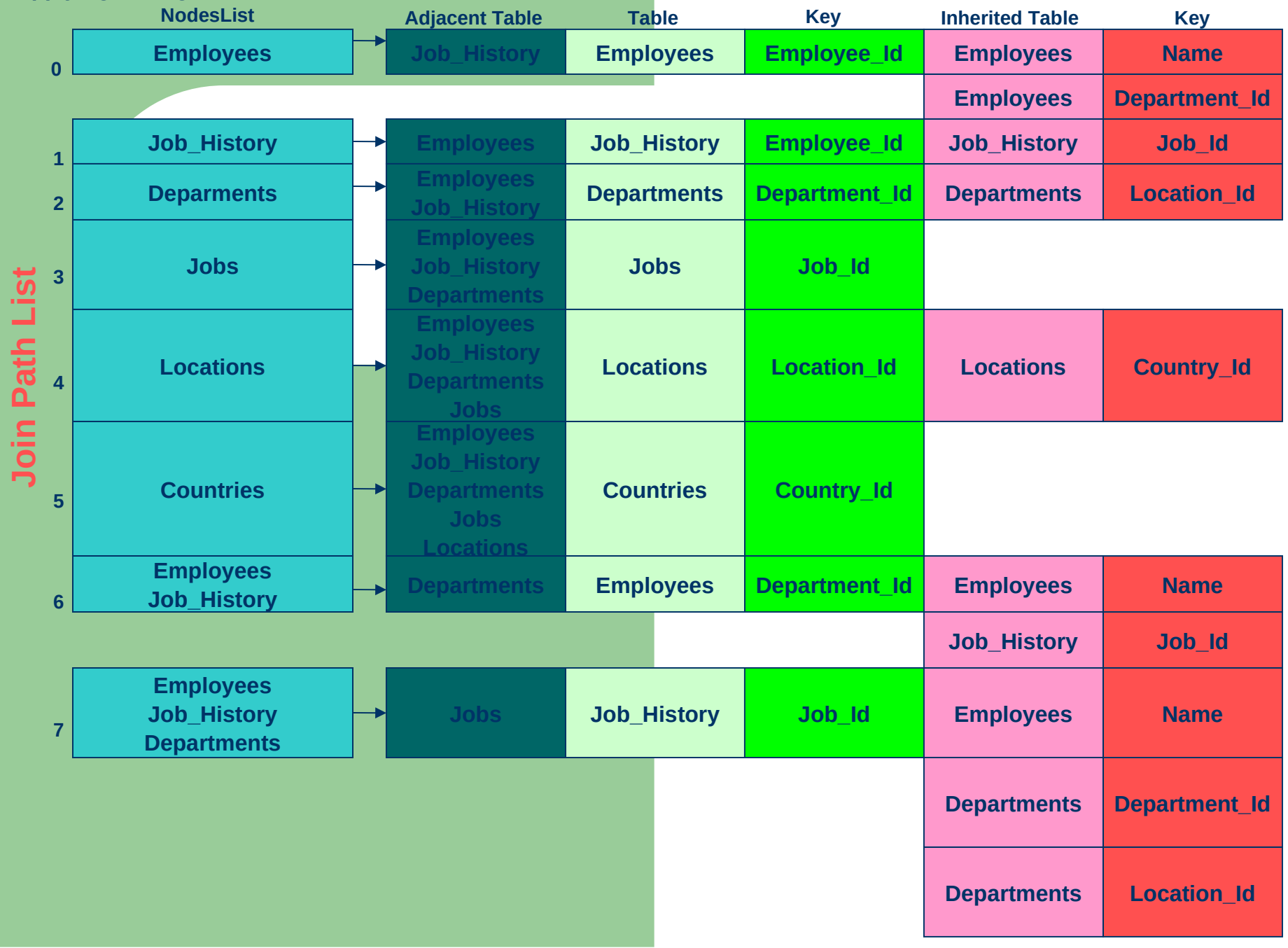
If the table is in join with itself, consider the table twice as aliases.

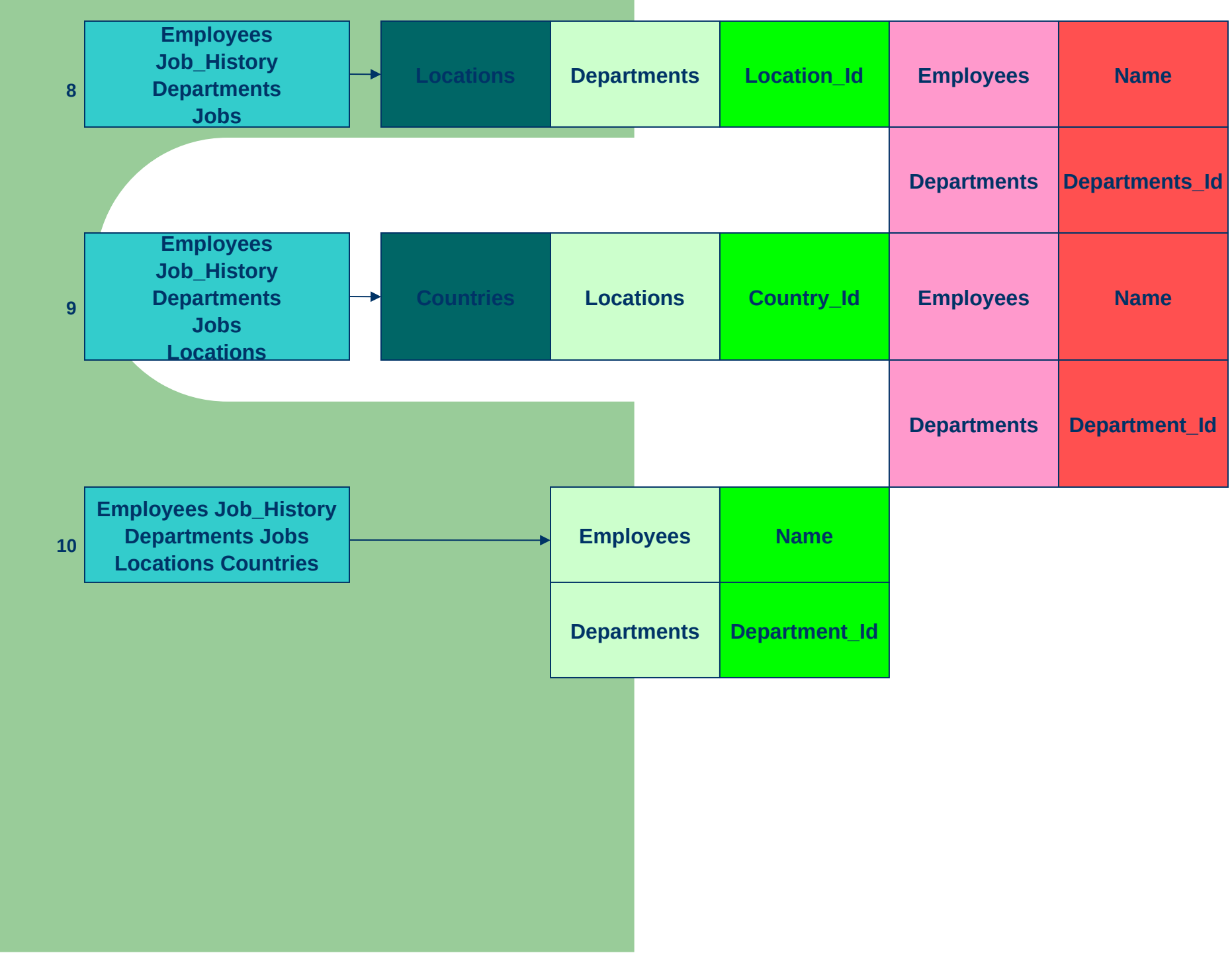
Define a Create Join Index (IndexName, Eventual columns for the last virtual table representing tables in join)

Implementation:

Use a big buffer and from the Data Dictionary divide it by the keys length, inherited keys length and space for the number of Data Pointers.

Suppose we wants the join sequence of the tables ordered by Employees.Name and Departments.Department_Id, applying the algorithm, the JoinPathList becomes:




8
Employees
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Jobs
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Countries
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Departments
Department_Id
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Employees Job_History
Departments Jobs
Locations Countries
Employees
Name
Departments
Department_Id

Insert routine

When a new row R_m from table T_i get inserted do the following:

- Locate the entry of T_i in the JoinPathList
- From its adjacent List, locate the definition of the keys and inherited keys
- From Row R_m get the columns constituting the keys and the inherited keys
- Call AddJoinKey (T_i, Keys, InheritedKeys, DP_i) where DP_i is the row id of row R_m.

AddJoinKey ($T_{[i]}$, $[DP_i]$)

- Call AddKey ($B^+Tree(T_{[i]})$, $keys_{[i]}$, $InheritedKeys_{[i]}$, $[DP_i]$) for the index of table $T_{[i]}$
- Locate the entry of $T_{[i]}$ in the JoinPathList
- From its adjacent List, locate the Table $T_{[k]}$ adjacent to it and do the following:
  - Locate the entry of $T_{[k]}$ in the JoinPathList
  - FindKey($B^+Tree(T_{[k]})$, $Keys_{[i]}$)
  - While found(keys[i]) do
    - ReturnKeys($B^+Tree(T_{[k]})$, $keys_{[k]}$, $InheritedKeys_{[k]}$, $[DP_k]$)
    - Locate the entry of $T_{[ik]}$ in the JoinPathList
    - From its adjacent List, locate the definition of the keys and inherited keys
    - From $keys_{[i],}$ $inheritedkeys_{[i]}$, $keys_{[k],}$ $inheritedkeys_{[k]}$ get the keys and inherited keys of $T_{[ik]}$
    - AddJoinKey ($T_{[ik]}$, $Keys_{[ik]}$, $InheritedKeys_{[ik]}$, $[DP_{ik}]$)
    - NextKey($B^+Tree(T_{[k]})$, $Keys_{[i]}$)

AddJoinKey ($T_{[i]}$, [DP_i])

In the same fashion when using an ordinary B^+Tree and one row get inserted, so we check the definition of the B^+Tree to get the necessary keys from the row to insert them, with B^{Join}Tree we check the definition to get the keys and the inherited keys.

Call AddjoinKey(T_i,[keys],[DP_i])

Delete routine

Call DelJoinKey (T_i, DP_i) where DP_i is the data pointer of the deleted row from the base table T_i.

DelJoinKey ($T_{[i]}$, $[DP_i]$)

- Call DelKey ($B^+Tree(T_{[i]})$, $keys_{[i]}$, $[DP_i]$) for the index of table $T_{[i]}$
- Locate the entry of $T_{[i]}$ in the JoinPathList
- From its adjacent List, locate the Table $T_{[k]}$ adjacent to it and do the following:
  - Locate the entry of $T_{[k]}$ in the JoinPathList
  - FindKey($B^+Tree(T_{[k]})$, $Keys_{[i]}$)
  - While found(keys[i]) do

    ReturnKeys($B^+Tree(T_{[k]})$, $keys_{[k]}$, $InheritedKeys_{[k]}$, $[DP_k]$)

    Locate the entry of $T_{[ik]}$ in the JoinPathList

    From its adjacent List, locate the definition of the keys and inherited keys

    From $keys_{[i],}$ $inheritedkeys_{[i]}$, $keys_{[k],}$ $inheritedkeys_{[k]}$ get the keys and inherited keys of $T[_{ik]}$

    DelJoinKey ($T_{[ik]}$, $Keys_{[ik]}$, $[DP_{ik}]$)

    NextKey($B^+Tree(T_{[k]})$, $Keys_{[i]}$)

B⋈Tree with incremental Join

Due to the fact that join is commutative and associative and we are working on Virtual Tables and using indexes on them; it is possible instead of calculating all the join combinations to calculate incrementally the join.

This issue works just when the n tables are in direct path join between them but if they are not we are not interested.

Giving a casual order for the tables.

Beginning from Table 0, get a table T_i in direct join with it.

A Join Path List comes out with 2 entries from T_o to T_i and from T_i to T_0.

The index number start always with 0.

Repeat, with T_{0i} and get a next table that is in direct join with T_0 or with T_i, the process continue till we scan all the tables.

This algorithm is linear, is 2*n – 1.

Complexity of the algorithm for the creation of JoinPathList.

The complexity for the creation of JoinPathList structure is:
2*n-1 where n is the number of tables in join.

Proof:
We can prove it by induction on the number of tables in join.

For m = 1:

The complexity should be 2*1-1 = 1 in fact it is the only table that get inserted in the JoinPathList.

For m = n-1:

Suppose that the number of tables in JoinPathList is 2*(n-1)-1.

For m = n:

The n^{th} table get inserted as a Vertex in the JoinPathList at the beginning of the algorithm.

The n^{th} table get inserted in queue and path dynamic arrays because the n tables are in join and at least there is one table in the (n-1) remaining table that is in join with the n^{th} table.

So when the algorithm run at certain point should execute:

$$\mathbf{T_{[buf]} + = T_i}$$

$$\mathbf{Insert\ NodesList[T_{[buf]}] = T_{[buf]}}$$

where T_l is $T_{n,}$ so the number of tables in JoinPathList are: 2*(n-1)-1 + 1 + 1 = 2*n-1

Complexity of the algorithm for the insertion and deletion.

Delete is symmetric to insert in the algorithm in the sense where there is an insert we use a delete, so they have both the same complexity.

When inserting a new row in the database we use the $B^{Join}Tree$ structure to drive us in the insert for the join.

Suppose that the order of the $B^{+}Tree$ is m, the number of elements in the (2*n-1) $B^{+}Trees$ is p_i where i is the index of the B+Tree and that in average there is l_i elements satisfying the join between every pair of tables.

In the worst case when get inserted row with the lowest order tables T_0 and T_1 in this case we call recursively the insert procedure for (2*n – 1) – (n - 1) = n times.

The complexity will be: $Ord(n * l_i * \log_{m/2}(p_i))$

Complexity of the algorithm for the other operation.

The only B^+Tree of our interest for the scan is the one with the latest index that have the join of the tables inside it.

Suppose that the number of elements for the latest index is $p_{(2*n-1)}$ so the other operations on this B^+Tree for find, search, prev, next,… are the same as for normal B^+Tree with the same number of elements.

Steps to generate Join Path List for the join sequence $T_0 \ldots T_m$

insert all the Names of Base Tables from the join sequence $T_0 \ldots T_m$ as vertexes in the PathJoinList

create 2 dynamic arrays queue and path

insert T_0 into path

insert T_0 into queue

repeat

- **$T_{Element}$ = First Table in queue**
- **for every Link Item in Adjacent Link of $T_{Element}$ from the Join Graph do**
  - **if the Link Item is in the join sequence then**
    - **if path doesn't contain the Link Item then**
      - **insert Link Item into path**
      - **insert Link Item into queue**
- **remove $T_{Element}$ from queue**

until queue is empty

Steps to generate Join Path List for the join sequence $T_0 \ldots T_m$ (continue)

create a local buffer buf

insert into buf the first entry from path

for all the remainder entries in path do

- **take one T_i at a time**
- **PathJoinAdjacentList(T_i) = $T_{[buf]}$**
- **Key(T_i) = getFirstAdjacentListKey(T_i,$T_{[buf]}$)**
- **PathJoinAdjacentList($T_{[buf]}$) = T_i**
- **Key($T_{[buf]}$) = getFirstAdjacentListKey ($T_{[buf]}$,T_i)**
- **$T_{[buf]}$ + = T_i**
- **Insert NodesList[$T_{[buf]}$] = $T_{[buf]}$**

Steps to generate Join Path List for the join sequence $T_0 \ldots T_m$ (continue)

create a structure buf with 2 fields: Table and Key

for all the tables in PathJoinList going downward do

take one $T_{[i]}$ at a time

for all Base Tables in$T_{[i]}$ do

take one T_k at a time

for every buf.Table = T_k do

if (buf.key != Key($T_{[i]}$)) and (buf.Key not in AuxKey($T_{[i]}$)) then AuxKey($T_{[i]}$) += buf.key

if T_l is the table from which comes Key($T_{[i]}$) then

buf.Table = T_l

buf.key = Key($T_{[i]}$)