Announcements
Database Management Systems
Database Management System Architecture

Architecture of a Database System by Hellerstein, Stonebreaker, and Hamilton
Query Planning

The manner in which tables are filtered, sorted, and joined affects execution time.
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Select the parents of curly-furred dogs:

```sql
select parent from parents, dogs
where child = name and fur = "curly";
```
Query Planning

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select parent from parents, dogs
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Join all rows of parents to all rows of dogs, filter by `child = name` and `fur = "curly"`
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```sql
select parent
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where child = name and fur = "curly";
```

Join all rows of parents to all rows of dogs, filter by `child = name` and `fur = "curly"`

Join only rows of parents and dogs where `child = name`, filter by `fur = "curly"`
Query Planning

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Select the parents of curly-furred dogs:

```sql
select parent from parents, dogs
where child = name and fur = "curly";
```

Join all rows of parents to all rows of dogs, filter by `child = name` and `fur = "curly"`

Join only rows of parents and dogs where `child = name`, filter by `fur = "curly"`

Filter dogs by `fur = "curly"`, join result with all rows of parents, filter by `child = name`
Query Planning

The manner in which tables are filtered, sorted, and joined affects execution time

Select the parents of curly-furred dogs:

```
select parent from parents, dogs
where child = name and fur = "curly";
```

Join all rows of parents to all rows of dogs, filter by child = name and fur = "curly"

Join only rows of parents and dogs where child = name, filter by fur = "curly"

Filter dogs by fur = "curly", join result with all rows of parents, filter by child = name

Filter dogs by fur = "curly", join only rows of result and parents where child = name
Local Tables
Local Tables

A `create table` statement names a table globally
Local Tables

A create table statement names a table globally

create table parents as
    select "abraham" as parent, "barack" as child union
    select "abraham" , "clinton" union
    select "delano" , "herbert" union
    select "fillmore" , "abraham" union
    select "fillmore" , "delano" union
    select "fillmore" , "grover" union
    select "eisenhower" , "fillmore";
Local Tables

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create table parents as
  select "abraham" as parent, "barack" as child union
  select "abraham" , "clinton" union
  select "delano" , "herbert" union
  select "fillmore" , "abraham" union
  select "fillmore" , "delano" union
  select "fillmore" , "grover" union
  select "eisenhower" , "fillmore";

table contents:

<table>
<thead>
<tr>
<th>Parent</th>
<th>Child</th>
</tr>
</thead>
<tbody>
<tr>
<td>abraham</td>
<td>barack</td>
</tr>
<tr>
<td>abraham</td>
<td>clinton</td>
</tr>
<tr>
<td>delano</td>
<td>herbert</td>
</tr>
<tr>
<td>fillmore</td>
<td>abraham</td>
</tr>
<tr>
<td>fillmore</td>
<td>delano</td>
</tr>
<tr>
<td>fillmore</td>
<td>grover</td>
</tr>
<tr>
<td>eisenhower</td>
<td>fillmore</td>
</tr>
</tbody>
</table>
Local Tables

A `create table` statement names a table globally

create table parents as
select "abraham" as parent, "barack" as child union
...

parents:

Eisenhower
↓
Fillmore

Abraham

Delano

Grover

Barack

Clinton

Herbert
Local Tables

A `create table` statement names a table globally.

A `with` clause of a `select` statement names a table that is local to the statement.

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    select "abraham" as parent, "barack" as child union
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    select "abraham" as parent, "barack" as child union
    ...
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```sql
create table parents as
    select "abraham" as parent, "barack" as child union ...
```

```
select parent from ...
```
Local Tables

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```
create table parents as
    select "abraham" as parent, "barack" as child union
...
```

with

```
select parent from ...
```

parents:

```
Abraham
Barack
Clinton
Delano
Eisenhower
Fillmore
Grover
Herbert
```
Local Tables

A `create table` statement names a table globally.

A `with` clause of a `select` statement names a table that is local to the statement.

```sql
create table parents as
  select "abraham" as parent, "barack" as child union
... with
  best(dog) as ( select parent from ...)
```
Local Tables

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create table parents as
  select "abraham" as parent, "barack" as child union
  ...

with
  best(dog) as (  
    select "eisenhower" union

select parent from ...
Local Tables

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```
create table parents as
  select "abraham" as parent, "barack" as child union
...
```

with

```
best(dog) as (  
  select "eisenhower" union
  select "barack"
)
```

select parent from ...

parents:

- Eisenhower
- Fillmore
- Abraham
- Delano
- Grover
- Barack
- Clinton
- Herbert
Local Tables

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  select "abraham" as parent, "barack" as child union ...

with
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    select "eisenhower" union
    select "barack"
  )
select parent from ...
```

<table>
<thead>
<tr>
<th>dog</th>
</tr>
</thead>
<tbody>
<tr>
<td>eisenhower</td>
</tr>
<tr>
<td>barack</td>
</tr>
</tbody>
</table>
Local Tables

A `create table` statement names a table globally

A `with` clause of a `select` statement names a table that is local to the statement

```sql
create table parents as
  select "abraham" as parent, "barack" as child union 
...
with
  best(dog) as ( 
    select "eisenhower" union 
    select "barack"
  )
select parent from parents, best where child=dog;
```
Local Tables

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A `with` clause of a `select` statement names a table that is local to the statement

```sql
create table parents as
    select "abraham" as parent, "barack" as child union

with
    best(dog) as (  
        select "eisenhower" union
        select "barack"
    )
select parent from parents, best where child=dog;
```

<table>
<thead>
<tr>
<th>dog</th>
</tr>
</thead>
<tbody>
<tr>
<td>eisenhower</td>
</tr>
<tr>
<td>barack</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>parent</th>
</tr>
</thead>
<tbody>
<tr>
<td>abraham</td>
</tr>
</tbody>
</table>
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create table parents as
    select "abraham" as parent, "barack" as child union
    ...
with
    best(dog) as ( 
        select "eisenhower" union select "barack"
    )
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    select "abraham" as parent, "barack" as child union
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    best(dog) as (   
        select "eisenhower" union  
        select "barack"  
    )

select parent from parents, best where child=dog;

<table>
<thead>
<tr>
<th>parent</th>
</tr>
</thead>
<tbody>
<tr>
<td>abraham</td>
</tr>
</tbody>
</table>

`best`:

<table>
<thead>
<tr>
<th>dog</th>
</tr>
</thead>
<tbody>
<tr>
<td>eisenhower</td>
</tr>
<tr>
<td>barack</td>
</tr>
</tbody>
</table>

parents:

Local table only exists for this select

Part of the select statement
Local Tables

A create table statement names a table globally

A with clause of a select statement names a table that is local to the statement

create table parents as
    select "abraham" as parent, "barack" as child union
... Part of the select statement
with
    best(dog) as (  
        select "eisenhower" union
        select "barack"
    )
select parent from parents, best where child=dog;

(Demo)
Example: Relationships

with

what(first, second) as (  
    select a.child, b.child  
    from parents as a, parents as b  
    where a.parent = b.parent and  
        a.child != b.child

)

select child as ____________, second as ____________  
from parents, what where parent=first;
(A) What are appropriate names for the columns in this result?

```
with
    what(first, second) as (  
        select a.child, b.child  
        from parents as a, parents as b  
        where a.parent = b.parent and  
            a.child != b.child  
    )
select child as ____________, second as ____________
    from parents, what where parent=first;
```
Example: Relationships

(A) What are appropriate names for the columns in this result?

(B) How many rows and columns will result?

with

what(first, second) as (  
    select a.child, b.child  
    from parents as a, parents as b  
    where a.parent = b.parent and  
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)

select child as __________, second as __________  
from parents, what where parent=first;
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(A) What are appropriate names for the columns in this result?

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```sql
with siblings
what(first, second) as (
    select a.child, b.child
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select child as __________, second as __________
from parents, what where parent=first;
```

<table>
<thead>
<tr>
<th>parent</th>
<th>child</th>
<th>first</th>
<th>second</th>
</tr>
</thead>
<tbody>
<tr>
<td>abraham</td>
<td>barack</td>
<td>abraham</td>
<td>delano</td>
</tr>
</tbody>
</table>
Example: Relationships

(A) What are appropriate names for the columns in this result?

(B) How many rows and columns will result?

```
with siblings what((first, second) as (  
  select a.child, b.child  
  from parents as a, parents as b  
  where a.parent = b.parent and  
      a.child != b.child  
)
)
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from parents, what where parent=first;
```

<table>
<thead>
<tr>
<th>parent</th>
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<td>abraham</td>
<td>delano</td>
</tr>
</tbody>
</table>
Example: Relationships

(A) What are appropriate names for the columns in this result?

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    select a.child, b.child 
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    where a.parent = b.parent and 
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select child as __________, second as __________
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<table>
<thead>
<tr>
<th>parent</th>
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Example: Relationships

(A) What are appropriate names for the columns in this result?

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    select a.child, b.child 
    from parents as a, parents as b 
    where a.parent = b.parent and 
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)

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from parents, what
where parent=first;
```

<table>
<thead>
<tr>
<th>parent</th>
<th>child</th>
<th>first</th>
<th>second</th>
</tr>
</thead>
<tbody>
<tr>
<td>abraham</td>
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<td>abraham</td>
<td>delano</td>
</tr>
</tbody>
</table>
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    select a.child, b.child  
    from parents as a, parents as b  
    where a.parent = b.parent and  
    a.child != b.child  
)

select child as __________, second as __________  
from parents, what where parent=first;
```

<table>
<thead>
<tr>
<th>parent</th>
<th>child</th>
<th>first</th>
<th>second</th>
</tr>
</thead>
<tbody>
<tr>
<td>abraham</td>
<td>barack</td>
<td>abraham</td>
<td>delano</td>
</tr>
</tbody>
</table>

siblings

parents:

- Eisenhower
- Fillmore
- Abraham
- Barack
- Clinton
- Delano
- Herbert
- Grover

- Uncle
- Nephew
Recursive Local Tables
Local Tables can be Declared Recursively
Local Tables can be Declared Recursively

An ancestor is your parent or an ancestor of your parent
Local Tables can be Declared Recursively

An ancestor is your parent or an ancestor of your parent

create table parents as
  select "abraham" as parent, "barack" as child union
  ...

parents:
  
  Eisenhower -> Fillmore
  Fillmore -> Abraham, Delano, Grover
  Abraham -> Barack, Clinton, Herbert
Local Tables can be Declared Recursively

An ancestor is your parent or an ancestor of your parent

create table parents as
    select "abraham" as parent, "barack" as child union
    ...

parents:
  Eisenhower
  Fillmore
  Abraham
  Delano
  Grover
  Barack
  Clinton
  Herbert
Local Tables can be Declared Recursively

An ancestor is your parent or an ancestor of your parent

create table parents as
  select "abraham" as parent, "barack" as child union
  ...

ancestors(ancestor, descendent)
Local Tables can be Declared Recursively

An ancestor is your parent or an ancestor of your parent

```sql
create table parents as
    select "abraham" as parent, "barack" as child union
    ...

ancestors(ancestor, descendent) as (  
    select parent, child from parents union  
    select ancestor, child  
        from ancestors, parents  
        where parent = descendent
)
```
Local Tables can be Declared Recursively

An ancestor is your parent or an ancestor of your parent

create table parents as
  select "abraham" as parent, "barack" as child union
    ...

with

ancestors(ancestor, descendent) as ( 
  select parent, child from parents union
  select ancestor, child
    from ancestors, parents
    where parent = descendent
)

select ancestor from ancestors where descendent="herbert";
Local Tables can be Declared Recursively

An ancestor is your parent or an ancestor of your parent

```sql
create table parents as
  select "abraham" as parent, "barack" as child union ...
with
ancestors(ancestor, descendent) as (
  select parent, child from parents union
  select ancestor, child
  from ancestors, parents
  where parent = descendent
)
select ancestor from ancestors where descendent="herbert";
```

<table>
<thead>
<tr>
<th>ancestor</th>
</tr>
</thead>
<tbody>
<tr>
<td>delano</td>
</tr>
<tr>
<td>fillmore</td>
</tr>
<tr>
<td>eisenhower</td>
</tr>
</tbody>
</table>
Global Names for Recursive Tables

To create a table with a global name, you need to select the contents of the local table.
Global Names for Recursive Tables

To create a table with a global name, you need to select the contents of the local table

create table odds as
  with
    odds(n) as (  
      select 1 union
      select n+2 from odds where n < 15
    )
  select n from odds;

Global Names for Recursive Tables

To create a table with a global name, you need to select the contents of the local table

```sql
create table odds as
    with
        odds(n) as (
            select 1 union
            select n+2 from odds where n < 15
        )
    select n from odds;
```

<table>
<thead>
<tr>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>13</td>
</tr>
<tr>
<td>15</td>
</tr>
</tbody>
</table>
Global Names for Recursive Tables

To create a table with a global name, you need to select the contents of the local table

```sql
create table odds as
with
    odds(n) as (            | odds: |
    select 1 union         | n    |
    select n+2 from odds where n < 15 | 1    |
)                        | 3    |
select n from odds;      | 5    |
```
Global Names for Recursive Tables

To create a table with a global name, you need to select the contents of the local table

```
create table odds as
with
  odds(n) as (
    select 1 union
    select n+2 from odds where n < 15;
  )
select n from odds;
```

Which names above can change without affecting the result?
Global Names for Recursive Tables

To create a table with a global name, you need to select the contents of the local table

```
create table odds as
    with
        odds(n) as (  
            select 1 union
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        )
    select n from odds;
```

Which names above can change without affecting the result?
Limits on Recursive Select Statements
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Recursive table definitions are only possible within a with clause
Limits on Recursive Select Statements

Recursive table definitions are only possible within a with clause

No mutual recursion: two or more tables cannot be defined in terms of each other
Limits on Recursive Select Statements

Recursive table definitions are only possible within a with clause.

No mutual recursion: two or more tables cannot be defined in terms of each other.

```sql
with
    odds(x) as (
      select 1 union select x+1 from evens
    ),
    evens(x) as (
      select x+1 from odds
    )
select x from odds
```
Limits on Recursive Select Statements

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```sql
with
  odds(x) as (  
    select 1 union select x+1 from evens
  ),
  evens(x) as (  
    select x+1 from odds
  )
select x from odds
```
Limits on Recursive Select Statements

Recursive table definitions are only possible within a with clause.

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with
    odds(x) as (  
        select 1 union select x+1 from evens 
    ),
    evens(x) as (  
        select x+1 from odds 
    )
select x from odds
```

No tree recursion: the table being defined can only appear once in a from clause.
Limits on Recursive Select Statements

Recursive table definitions are only possible within a with clause

No mutual recursion: two or more tables cannot be defined in terms of each other

```sql
with
    odds(x) as (  
        select 1 union select x+1 from evens  
    ),
    evens(x) as (  
        select x+1 from odds  
    )
select x from odds
```

No tree recursion: the table being defined can only appear once in a from clause

```sql
with
    ints(x) as (  
        select 1 union  
        select x-1 from ints union  
        select x+1 from ints  
    )
select x from ints;
```
Limits on Recursive Select Statements

Recursive table definitions are only possible within a with clause.

No mutual recursion: two or more tables cannot be defined in terms of each other.

```sql
with
  odds(x) as (  
    select 1 union select x+1 from evens
  ),
  evens(x) as (  
    select x+1 from odds
  )
select x from odds
```

No tree recursion: the table being defined can only appear once in a from clause.

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    select x+1 from ints
  )
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Limits on Recursive Select Statements

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    ),
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    )
select x from odds
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No tree recursion: the table being defined can only appear once in a from clause

```sql
with
    ints(x) as (  
        select 1 union  
        select x-1 from ints union  
        select x+1 from ints
    )
select x from ints;
```

```sql
with
    ints(x) as (  
        select a.x + b.x  
        from ints as a, ints as b
    )
select x from ints;
```
Limits on Recursive Select Statements

Recursive table definitions are only possible within a with clause.

No mutual recursion: two or more tables cannot be defined in terms of each other.

```sql
with
  odds(x) as ( select 1 union select x+1 from evens ),
  evens(x) as ( select x+1 from odds )
select x from odds
```

No tree recursion: the table being defined can only appear once in a from clause.

```sql
with
  ints(x) as ( select 1 union select x-1 from ints union select x+1 from ints )
select x from ints;
```

```sql
with
  ints(x) as ( select a.x + b.x from ints as a, ints as b )
select x from ints;
```
String Examples
Language is Recursive
Language is Recursive

Noun phrases can contain relative pronouns that introduce relative clauses
Language is Recursive

Noun phrases can contain relative pronouns that introduce relative clauses

The dog chased the cat
Language is Recursive

Noun phrases can contain relative pronouns that introduce relative clauses

The dog chased the cat

that chased the bird
Language is Recursive

Noun phrases can contain relative pronouns that introduce relative clauses

The dog chased the cat

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Language is Recursive

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The dog chased the cat

that chased the bird

The dog chased the cat

that the bird chased

The dog chased the cat

the bird chased
Language is Recursive

Noun phrases can contain relative pronouns that introduce relative clauses

The dog chased the cat
that chased the bird

The dog chased the cat
that the bird chased

The dog chased the cat
the bird chased

The dog the bird the cat chased chased chased me
Language is Recursive

Noun phrases can contain relative pronouns that introduce relative clauses

The dog chased the cat

that chased the bird

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The dog the bird the cat chased chased chased me

Bulldogs bulldogs bulldogs fight fight fight
Language is Recursive

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(Demo)
Integer Examples
Input-Output Tables

A table containing the inputs to a function can be used to map from output to input.
**Input-Output Tables**

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```sql
create table pairs as
with
  i(n) as (  
    select 1 union  
    select n+1 from i where n < 50  
  )
select a.n as x, b.n as y from i as a, i as b where a.n <= b.n;
```
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What integers can I add/multiply together to get 24?
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(Demo)
Example: Pythagorean Triples

All triples $a, b, c$ such that $a^2 + b^2 = c^2$
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All triples $a$, $b$, $c$ such that $a^2 + b^2 = c^2$

<table>
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<tr>
<th>$a$</th>
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All triples $a, b, c$ such that $a^2 + b^2 = c^2$

with

$$i(n) \text{ as } ($$

$$\text{select 1 union select n+1 from i where n < 20}$$

$$)$$

$$\text{select a.n as a, b.n as b, c.n as c}$$

$$\text{from } \ldots$$

$$\text{where } \ldots \text{ and } a.n*a.n + b.n*b.n = c.n*c.n;$$
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\text{select} & \ 1 \ \text{union select} \ n+1 \ \text{from} \ i \ \text{where} \ n < 20 \\
\text{select} & \ a.n \ \text{as} \ a, \ b.n \ \text{as} \ b, \ c.n \ \text{as} \ c
\end{align*}
\]

from ________________ i as a, i as b, i as c

\[
\text{where } a.n < b.n \ 	ext{and} \ a.n*a.n + b.n*b.n = c.n*c.n;
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Example: Fibonacci Sequence
Example: Fibonacci Sequence

Computing the next Fibonacci number requires both the previous and current numbers.
Example: Fibonacci Sequence

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Example: Fibonacci Sequence

Computing the next Fibonacci number requires both the previous and current numbers.

create table fibs as

    with

        fib(previous, current) as ( 
            select 0, 1 union

            select current, previous+current from fib

            where current <= ________________
        )

    select ________________ as n from fib;

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create table fibs as

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        fib(previous, current) as (  
            select 0, 1 union
            select current, previous + current from fib
            where current <= _________________
        )

        select _________________ as n from fib;

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Computing the next Fibonacci number requires both the previous and current numbers

```sql
create table fibs as
with
  fib(previous, current) as ( 
    select 0, 1 union
    select current, previous+current from fib
    where current <= 13
  )
select previous as n from fib;
```

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Local table
A Very Interesting Number

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