Common Table Expressions (CTEs) allow queries to be more imperative, allowing looping and processing hierarchical structures that are normally associated only with imperative languages.

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Last updated: December, 2019
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1. Imperative vs. Declarative
In computer science, **imperative** programming is a programming paradigm that describes computation in terms of statements that change a program state. In much the same way that imperative mood in natural languages expresses commands to take action, imperative programs define sequences of commands for the computer to perform.

http://en.wikipedia.org/wiki/Imperative_programming
Declarative Programming Languages

The term is used in opposition to declarative programming, which expresses what the program should accomplish without prescribing how to do it in terms of sequence.
**Imperative**

**BASIC:**

```
10 PRINT "Hello";
20 GOTO 10
```

**C:**

```
while (1)
    printf("Hello\n");
```

**Perl:**

```
print("Hello\n") while (1);
```
SQL:

SELECT 'Hello'
UNION ALL
SELECT 'Hello'
UNION ALL
SELECT 'Hello'
UNION ALL
SELECT 'Hello'

...

An infinite loop is not easily implemented in simple SQL.
Imperative Database Options

- Client application code (e.g., libpq, JDBC, DBD::Pg)
- Server-side programming (e.g., PL/pgSQL, PL/Perl, C)
- Common table expressions
2. Syntax

https://www.flickr.com/photos/kylewhitney/
WITH [ RECURSIVE ] with_query_name [( column_name [, ...] )] AS 
( select ) [, ..., ]
SELECT ...
Keep Your Eye on the Red (Text)

https://www.flickr.com/photos/alltheaces/
WITH source AS (  
    SELECT 1
  )
SELECT * FROM source;

?column?

---------

1

The CTE created a source table that was referenced by the outer SELECT. All queries in this presentation can be downloaded from http://momjian.us/main/writings/pgsql/cte.sql.
WITH source AS (
    SELECT 1 AS col1
)
SELECT * FROM source;

The CTE returned column is source.col1.
The Column Can Also Be Named in the WITH Clause

```sql
WITH source (col1) AS ( 
    SELECT 1
)
SELECT * FROM source;
```

<table>
<thead>
<tr>
<th>col1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
</tbody>
</table>
Columns Can Be Renamed

WITH source (col2) AS (  
    SELECT 1 AS col1
  )  
SELECT col2 AS col3 FROM source;  
col3

---

1

The CTE column starts as *col1*, is renamed in the WITH clause as *col2*, and the outer SELECT renames it to *col3*. 
### Multiple CTE Columns Can Be Returned

WITH source AS (  
    SELECT 1, 2  
)  
SELECT * FROM source;  

<table>
<thead>
<tr>
<th>column?</th>
<th>column?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
SELECT 1
UNION
SELECT 1;
?column?
---------
  1

SELECT 1
UNION ALL
SELECT 1;
?column?
---------
  1
  1
Possible To Create Multiple CTE Results

WITH source AS (  
    SELECT 1, 2
  ),
  source2 AS (  
    SELECT 3, 4
  )
SELECT * FROM source
UNION ALL
SELECT * FROM source2;

<table>
<thead>
<tr>
<th>?column?</th>
<th>?column?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
WITH source AS ( 
    SELECT lanname, rolname 
    FROM pg_language JOIN pg_roles ON lanowner = pg_roles.oid
)
SELECT * FROM source;

<table>
<thead>
<tr>
<th>lanname</th>
<th>rolname</th>
</tr>
</thead>
<tbody>
<tr>
<td>internal</td>
<td>postgres</td>
</tr>
<tr>
<td>c</td>
<td>postgres</td>
</tr>
<tr>
<td>sql</td>
<td>postgres</td>
</tr>
<tr>
<td>plpgsql</td>
<td>postgres</td>
</tr>
</tbody>
</table>
WITH source AS (  
    SELECT lanname, rolname  
    FROM pg_language JOIN pg_roles ON lanowner = pg_roles.oid  
    ORDER BY lanname  
  )  
SELECT * FROM source  
UNION ALL  
SELECT MIN(lanname), NULL  
FROM source;  
lanname | rolname  
--------+--------  
c       | postgres  
internal | postgres  
plpgsql  | postgres  
sql      | postgres  
c       |
WITH class AS (  
    SELECT oid, relname  
    FROM pg_class  
    WHERE relkind = 'r'  
  )  
SELECT class.relname, attname  
FROM pg_attribute, class  
WHERE class.oid = attrelid  
ORDER BY 1, 2  
LIMIT 5;  
  relname | attname  
----------+----------  
pg_aggregate | aggfinalfn  
pg_aggregate | aggfoid  
pg_aggregate | agginitval  
pg_aggregate | aggsortop  
pg_aggregate | aggtransfn
CASE
WHEN condition THEN result
ELSE result
END

For example:
SELECT col,
    CASE
        WHEN col > 0 THEN 'positive'
        WHEN col = 0 THEN 'zero'
        ELSE 'negative'
    END
FROM tab;
3. Recursive CTEs

https://www.flickr.com/photos/rbh/
WITH RECURSIVE source AS ( 
    SELECT 1
)
SELECT * FROM source;

This does not loop because source is not mentioned in the CTE.
SET statement_timeout = '1s';

WITH RECURSIVE source AS (  
    SELECT 1  
    UNION ALL  
    SELECT 1 FROM source  
  )  
SELECT * FROM source;  
ERROR: canceling statement due to statement timeout
WITH RECURSIVE source AS (  
    SELECT 1  
    UNION ALL  
    SELECT 1 FROM source  
)  
SELECT * FROM source;
WITH RECURSIVE source AS (  
    SELECT 'Hello'
    UNION ALL
    SELECT 'Hello' FROM source
  )
SELECT * FROM source;
ERROR: canceling statement due to statement timeout

RESET statement_timeout;
WITH RECURSIVE source AS (  
    SELECT 'Hello'
    UNION
    SELECT 'Hello' FROM source
  )
SELECT * FROM source;
?column?
----------
Hello
WITH RECURSIVE source (counter) AS (  
    -- seed value  
    SELECT 1  
    UNION ALL  
    SELECT counter + 1  
    FROM source  
    -- terminal condition  
    WHERE counter < 10  
)  
SELECT * FROM source;
Of course, this can be more easily accomplished using `generate_series(1, 10)`.
for (my $i = 1; $i <= 10; $i++) {
    print "$i\n";
}

sub f
{
    my $arg = shift;
    print "$arg\n";
    f($arg + 1) if ($arg < 10);
}

f(1);
my @table;
sub f
{
    my $arg = shift // 1;
    push @table, $arg;
    f($arg + 1) if ($arg < 10);
}
f();
map {print "$_\n"} @table;

This is the most accurate representation of CTEs because it accumulates results in an array (similar to a table result).
4. Examples

https://www.flickr.com/photos/82134796@N03/
WITH RECURSIVE source (counter, product) AS (  
    SELECT 1, 1  
    UNION ALL  
    SELECT counter + 1, product * (counter + 1)  
    FROM source  
    WHERE counter < 10  
)  
SELECT counter, product FROM source;
<table>
<thead>
<tr>
<th>counter</th>
<th>product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td>6</td>
<td>720</td>
</tr>
<tr>
<td>7</td>
<td>5040</td>
</tr>
<tr>
<td>8</td>
<td>40320</td>
</tr>
<tr>
<td>9</td>
<td>362880</td>
</tr>
<tr>
<td>10</td>
<td>3628800</td>
</tr>
</tbody>
</table>
WITH RECURSIVE source (counter, product) AS ( 
    SELECT 1, 1 
    UNION ALL 
    SELECT counter + 1, product * (counter + 1) 
    FROM source 
    WHERE counter < 10 
)
SELECT counter, product 
FROM source 
WHERE counter = 10;

<table>
<thead>
<tr>
<th>counter</th>
<th>product</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3628800</td>
</tr>
</tbody>
</table>
```perl
my @table;
sub f {
    my ($counter, $product) = @_; 
    my ($counter_new, $product_new);
    if (!defined($counter)) {
        $counter_new = 1;
        $product_new = 1;
    } else {
        $counter_new = $counter + 1;
        $product_new = $product * ($counter + 1);
    }
    push(@table, [$counter_new, $product_new]);
    f($counter_new, $product_new) if ($counter < 10);
}
f();
map {print "@$_\n" if ($_->[0]) == 10} @table;
```
WITH RECURSIVE source (str) AS (  
    SELECT 'a'
    UNION ALL
    SELECT str || 'a'
    FROM source
    WHERE length(str) < 10
)
SELECT * FROM source;
str
--------------
a
aa
aaa
aaaa
aaaaa
aaaaaa
aaaaaaa
aaaaaaaa
aaaaaaaaa
aaaaaaaaaa
aaaaaaaaaaa
aaaaaaaaaaaaa
aaaaaaaaaaaa
aaaaaaaaaaaaa
aaaaaaaaaaaaa
aaaaaaaaaaaaaa
WITH RECURSIVE source (str) AS ( 
    SELECT 'a'
    UNION ALL
    SELECT str || chr(ascii(substr(str, length(str))) + 1)
    FROM source
    WHERE length(str) < 10
)
SELECT * FROM source;
Output

```
str
---------
a
ab
abc
abcd
abcde
abcdef
abcdefg
abcdefgh
abcdefghi
abcdefghij
```
WITH RECURSIVE source (counter) AS (
    SELECT -10
    UNION ALL
    SELECT counter + 1
    FROM source
    WHERE counter < 10
)
SELECT repeat(' ', 5 - abs(counter) / 2) ||
    'X' ||
    'X' ||
    repeat(' ', abs(counter)) ||
    'X'
FROM source;
WITH RECURSIVE source (counter) AS ( 
    SELECT -10 
    UNION ALL 
    SELECT counter + 1 
    FROM source 
    WHERE counter < 10 
)

SELECT counter, 
    repeat(' ', 5 - abs(counter) / 2) || 
    'X' || 
    repeat(' ', abs(counter)) || 
    'X' 
FROM source;

This generates Integers from -10 to 10, and these numbers are used to print an appropriate number of spaces.
| counter | ?column? |
|---------+----------|
| -10     | X X      |
| -9      | X X      |
| -8      | X X      |
| -7      | X X      |
| -6      | X X      |
| -5      | X X      |
| -4      | X X      |
| -3      | X X      |
| -2      | X X      |
| -1      | X X      |
| 0       | XX       |
| 1       | X X      |
| 2       | X X      |
| 3       | X X      |
| 4       | X X      |
| 5       | X X      |
| 6       | X X      |
| 7       | X X      |
| 8       | X X      |
| 9       | X X      |
| 10      | X X      |
WITH RECURSIVE source (counter) AS ( 
    SELECT -10 
    UNION ALL 
    SELECT counter + 1 
    FROM source 
    WHERE counter < 10 
) 
SELECT repeat(' ', abs(counter)/2) || 'X' || repeat(' ', 10 - abs(counter)) || 'X' 
FROM source;
A Diamond

?column?

------------------
 XX
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 X X
 XX
WITH RECURSIVE source (counter) AS (  
    SELECT -10  
    UNION ALL  
    SELECT counter + 1  
    FROM source  
    WHERE counter < 10  
)

SELECT repeat(' ', int4(pow(counter, 2)/10)) ||  
'X' ||  
repeat(' ', 2 * (10 - int4(pow(counter, 2)/10))) ||  
'X'  
FROM source;
An Oval
WITH RECURSIVE source (counter) AS (  
    SELECT -10  
    UNION ALL  
    SELECT counter + 1  
    FROM source  
    WHERE counter < 10
  )
SELECT repeat(' ', int4(pow(counter, 2)/5)) || 'X' || 
  repeat(' ', 2 * (20 - int4(pow(counter, 2)/5))) || 'X' 
FROM source;
Output

?column?

--------------------------------------------
Prime Factors

The prime factors of $X$ are the prime numbers that must be multiplied to equal $X$, e.g.:

- $10 = 2 \times 5$
- $27 = 3 \times 3 \times 3$
- $48 = 2 \times 2 \times 2 \times 2 \times 3$
- $66 = 2 \times 3 \times 11$
- $70 = 2 \times 5 \times 7$
- $100 = 2 \times 2 \times 5 \times 5$
WITH RECURSIVE source (counter, factor, is_factor) AS ( 
    SELECT 2, 56, false
    UNION ALL
    SELECT CASE WHEN factor % counter = 0 THEN counter ELSE counter + 1 END,
            CASE WHEN factor % counter = 0 THEN factor / counter ELSE factor END,
            CASE WHEN factor % counter = 0 THEN true ELSE false END
    FROM source
    WHERE factor <> 1
)
SELECT * FROM source;
### Output

<table>
<thead>
<tr>
<th>counter</th>
<th>factor</th>
<th>is_factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>56</td>
<td>f</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
<td>t</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>t</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>t</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>f</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>f</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>f</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>f</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>f</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>t</td>
</tr>
</tbody>
</table>

\[ \frac{55}{96} \]
WITH RECURSIVE source (counter, factor, is_factor) AS (  
    SELECT 2, 56, false  
    UNION ALL  
    SELECT  
        CASE  
            WHEN factor % counter = 0 THEN counter  
        ELSE counter + 1  
        END,  
        CASE  
            WHEN factor % counter = 0 THEN factor / counter  
        ELSE factor  
        END,  
        CASE  
            WHEN factor % counter = 0 THEN true  
        ELSE false  
        END  
    FROM source  
    WHERE factor <> 1  
)  
SELECT * FROM source WHERE is_factor;
| counter | factor | is_factor |
|---------+--------+-----------|
| 2       | 28     | t         |
| 2       | 14     | t         |
| 2       | 7      | t         |
| 7       | 1      | t         |

\[
\frac{57}{96}
\]
WITH RECURSIVE source (counter, factor, is_factor) AS ( 
    SELECT 2, 322434, false 
    UNION ALL 
    SELECT 
        CASE 
            WHEN factor % counter = 0 THEN counter 
        ELSE counter + 1 
        END, 
        CASE 
            WHEN factor % counter = 0 THEN factor / counter 
        ELSE factor 
        END, 
        CASE 
            WHEN factor % counter = 0 THEN true 
        ELSE false 
        END 
    FROM source 
    WHERE factor <> 1 
) 
SELECT * FROM source WHERE is_factor;
<table>
<thead>
<tr>
<th>counter</th>
<th>factor</th>
<th>is_factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>161217</td>
<td>t</td>
</tr>
<tr>
<td>3</td>
<td>53739</td>
<td>t</td>
</tr>
<tr>
<td>3</td>
<td>17913</td>
<td>t</td>
</tr>
<tr>
<td>3</td>
<td>5971</td>
<td>t</td>
</tr>
<tr>
<td>7</td>
<td>853</td>
<td>t</td>
</tr>
<tr>
<td>853</td>
<td>1</td>
<td>t</td>
</tr>
</tbody>
</table>
WITH RECURSIVE source (counter, factor, is_factor) AS ( 
    SELECT 2, 66, false 
    UNION ALL 
    SELECT 
        CASE 
            WHEN factor % counter = 0 THEN counter 
        END, 
        CASE 
            WHEN factor % counter = 0 THEN factor / counter 
        END, 
        CASE 
            WHEN factor % counter = 0 THEN true 
        END 
    FROM source 
    WHERE factor <> 1 
) 
SELECT * FROM source;
<table>
<thead>
<tr>
<th>counter</th>
<th>factor</th>
<th>is_factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>66</td>
<td>f</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>t</td>
</tr>
<tr>
<td>3</td>
<td>33</td>
<td>f</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>t</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>f</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>f</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
<td>f</td>
</tr>
<tr>
<td>7</td>
<td>11</td>
<td>f</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
<td>f</td>
</tr>
<tr>
<td>9</td>
<td>11</td>
<td>f</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>f</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>f</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>t</td>
</tr>
</tbody>
</table>
WITH RECURSIVE source (counter, factor, is_factor) AS (  
    SELECT 2, 66, false  
    UNION ALL  
    SELECT  
      CASE  
        WHEN factor % counter = 0 THEN counter  
        -- is 'factor' prime?  
        WHEN counter * counter > factor THEN factor  
        -- now only odd numbers  
        WHEN counter = 2 THEN 3  
        ELSE counter + 2  
      END,  
      CASE  
        WHEN factor % counter = 0 THEN factor / counter  
        ELSE factor  
      END,  
      CASE  
        WHEN factor % counter = 0 THEN true  
        ELSE false  
      END  
    FROM source  
    WHERE factor <> 1  
  )  
SELECT * FROM source;
| counter | factor | is_factor |
|---------+--------+-----------|
| 2       | 66     | f         |
| 2       | 33     | t         |
| 3       | 33     | f         |
| 3       | 11     | t         |
| 5       | 11     | f         |
| 11      | 11     | f         |
| 11      | 1      | t         |
WITH RECURSIVE source (counter, factor, is_factor) AS ( 
    SELECT 2, 66, false 
    UNION ALL 
    SELECT 
        CASE 
            WHEN factor % counter = 0 THEN counter 
            -- is 'factor' prime? 
            WHEN counter * counter > factor THEN factor 
            -- now only odd numbers 
            WHEN counter = 2 THEN 3 
            ELSE counter + 2 
        END, 
        CASE 
            WHEN factor % counter = 0 THEN factor / counter 
        ELSE factor 
        END, 
        CASE 
            WHEN factor % counter = 0 THEN true 
        ELSE false 
        END 
    FROM source 
    WHERE factor <> 1 
) 
SELECT * FROM source WHERE is_factor;
<table>
<thead>
<tr>
<th>counter</th>
<th>factor</th>
<th>is_factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>33</td>
<td>t</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>t</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>t</td>
</tr>
</tbody>
</table>
my @table;
sub f {
    my ($counter, $factor, $is_factor) = @_;  
    my ($counter_new, $factor_new, $is_factor_new);
    if (!defined($counter)) {
        $counter_new = 2;
        $factor_new = 66;
        $is_factor_new = 0;
    } else {
        $counter_new = ($factor % $counter == 0) ? $counter :
                    ($counter * $counter > $factor) ? $factor :
                    ($counter == 2) ? 3 :
                    $counter + 2;
        $factor_new = ($factor % $counter == 0) ? $factor / $counter :
                        $factor;
        $is_factor_new = ($factor % $counter == 0);
    }
    push(@table, [$counter_new, $factor_new, $is_factor_new]);
    f($counter_new, $factor_new) if ($factor != 1);
}
f();
map {print "$_->[0]$_->[1]$_->[2]\n" if ($_->[2]) == 1} @table;
CREATE TEMPORARY TABLE part (parent_part_no INTEGER, part_no INTEGER);

INSERT INTO part VALUES (1, 11);
INSERT INTO part VALUES (1, 12);
INSERT INTO part VALUES (1, 13);
INSERT INTO part VALUES (2, 21);
INSERT INTO part VALUES (2, 22);
INSERT INTO part VALUES (2, 23);
INSERT INTO part VALUES (11, 101);
INSERT INTO part VALUES (13, 102);
INSERT INTO part VALUES (13, 103);
INSERT INTO part VALUES (22, 221);
INSERT INTO part VALUES (22, 222);
INSERT INTO part VALUES (23, 231);
WITH RECURSIVE source (part_no) AS (  
  SELECT 2  
  UNION ALL  
  SELECT part.part_no  
  FROM source JOIN part ON (source.part_no = part.parent_part_no)  
)  
SELECT * FROM source;

Using UNION without ALL here would avoid infinite recursion if there is a loop in the data, but it would also cause a part with multiple parents to appear only once.
WITH RECURSIVE source (level, part_no) AS (
    SELECT 0, 2
    UNION ALL
    SELECT level + 1, part.part_no
    FROM source JOIN part ON (source.part_no = part.parent_part_no)
)
SELECT ' +' || repeat('-', level * 2) || part_no::text AS part_tree
FROM source;

<table>
<thead>
<tr>
<th>part_tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2</td>
</tr>
<tr>
<td>+--21</td>
</tr>
<tr>
<td>+--22</td>
</tr>
<tr>
<td>+--23</td>
</tr>
<tr>
<td>+----221</td>
</tr>
<tr>
<td>+----222</td>
</tr>
<tr>
<td>+----231</td>
</tr>
</tbody>
</table>
WITH RECURSIVE source (level, tree, part_no) AS (  
    SELECT 0, '2', 2  
    UNION ALL  
    SELECT level + 1, tree || ' ' || part.part_no::text, part.part_no  
    FROM source JOIN part ON (source.part_no = part.parent_part_no)  
)  
SELECT '+' || repeat('-', level * 2) || part_no::text AS part_tree, tree  
FROM source  
ORDER BY tree;  
| part_tree | tree  
|-----------+----------  
| +2        | 2        
| +--21     | 2 21     
| +--22     | 2 22     
| +----221  | 2 22 221 
| +----222  | 2 22 222 
| +--23     | 2 23     
| +----231  | 2 23 231 |
WITH RECURSIVE source (level, tree, part_no) AS ( 
    SELECT 0, '{2}'::int[], 2
    UNION ALL
    SELECT level + 1, array_append(tree, part.part_no), part.part_no
    FROM source JOIN part ON (source.part_no = part.parent_part_no)
)

SELECT '+' || repeat('-', level * 2) || part_no::text AS part_tree, tree
FROM source
ORDER BY tree;

<table>
<thead>
<tr>
<th>part_tree</th>
<th>tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2</td>
<td>{2}</td>
</tr>
<tr>
<td>+--21</td>
<td>{2,21}</td>
</tr>
<tr>
<td>+--22</td>
<td>{2,22}</td>
</tr>
<tr>
<td>+----221</td>
<td>{2,22,221}</td>
</tr>
<tr>
<td>+----222</td>
<td>{2,22,222}</td>
</tr>
<tr>
<td>+--23</td>
<td>{2,23}</td>
</tr>
<tr>
<td>+----231</td>
<td>{2,23,231}</td>
</tr>
</tbody>
</table>
WITH RECURSIVE source (level, tree, part_no) AS (
    SELECT 0, '{2}'::int[], 2
    UNION ALL
    SELECT level + 1, array_append(tree, part.part_no), part.part_no
    FROM source JOIN part ON (source.part_no = part.parent_part_no)
)

SELECT *, '+' || repeat('-', level * 2) || part_no::text AS part_tree
FROM source
ORDER BY tree;

<table>
<thead>
<tr>
<th>level</th>
<th>tree</th>
<th>part_no</th>
<th>part_tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>{2}</td>
<td>2</td>
<td>+2</td>
</tr>
<tr>
<td>1</td>
<td>{2,21}</td>
<td>21</td>
<td>+--21</td>
</tr>
<tr>
<td>1</td>
<td>{2,22}</td>
<td>22</td>
<td>+--22</td>
</tr>
<tr>
<td>2</td>
<td>{2,22,221}</td>
<td>221</td>
<td>+----221</td>
</tr>
<tr>
<td>2</td>
<td>{2,22,222}</td>
<td>222</td>
<td>+----222</td>
</tr>
<tr>
<td>1</td>
<td>{2,23}</td>
<td>23</td>
<td>+--23</td>
</tr>
<tr>
<td>2</td>
<td>{2,23,231}</td>
<td>231</td>
<td>+----231</td>
</tr>
</tbody>
</table>
CREATE TEMPORARY TABLE deptest (x1 INTEGER);
WITH RECURSIVE dep (classid, obj) AS (
    SELECT (SELECT oid FROM pg_class WHERE relname = 'pg_class'),
            oid
    FROM pg_class
    WHERE relname = 'deptest'
    UNION ALL
    SELECT pg_depend.classid, objid
    FROM pg_depend JOIN dep ON (refobjid = dep.obj)
)
SELECT (SELECT relname FROM pg_class WHERE oid = classid) AS class,
        (SELECT typname FROM pg_type WHERE oid = obj) AS type,
        (SELECT relname FROM pg_class WHERE oid = obj) AS class,
        (SELECT relkind FROM pg_class where oid = obj::regclass) AS kind,
        (SELECT adsrc FROM pg_attrdef WHERE oid = obj) AS attrdef,
        (SELECT conname FROM pg_constraint WHERE oid = obj) AS constraint
FROM dep
ORDER BY obj;
<table>
<thead>
<tr>
<th>class</th>
<th>type</th>
<th>class</th>
<th>kind</th>
<th>attrdef</th>
<th>constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>pg_class</td>
<td>_deptest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_type</td>
<td>deptest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_type</td>
<td>deptest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
WITH RECURSIVE dep (classid, obj) AS (  
    SELECT classid, objid  
    FROM pg_depend JOIN pg_class ON (refobjid = pg_class.oid)  
    WHERE relname = 'deptest'  
    UNION ALL  
    SELECT pg_depend.classid, objid  
    FROM pg_depend JOIN dep ON (refobjid = dep.obj)  
)  
SELECT (SELECT relname FROM pg_class WHERE oid = classid) AS class,  
    (SELECT typname FROM pg_type WHERE oid = obj) AS type,  
    (SELECT relname FROM pg_class WHERE oid = obj) AS class,  
    (SELECT relkind FROM pg_class where oid = obj::regclass) AS kind,  
    (SELECT adsrc FROM pg_attrdef WHERE oid = obj) AS attrdef,  
    (SELECT conname FROM pg_constraint WHERE oid = obj) AS constraint  
FROM dep  
ORDER BY obj;
<table>
<thead>
<tr>
<th>class</th>
<th>type</th>
<th>class</th>
<th>kind</th>
<th>attrdef</th>
<th>constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>pg_type</td>
<td>_deptest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_type</td>
<td>deptest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ALTER TABLE deptest ADD PRIMARY KEY (x1);
NOTICE: ALTER TABLE / ADD PRIMARY KEY will create implicit index "deptest_pkey" for table "deptest"
WITH RECURSIVE dep (classid, obj) AS (  
  SELECT (SELECT oid FROM pg_class WHERE relname = 'pg_class'),  
         oid  
  FROM pg_class  
  WHERE relname = 'deptest'  
  UNION ALL  
  SELECT pg_depend.classid, objid  
  FROM pg_depend JOIN dep ON (refobjid = dep.obj)  
)  
SELECT (SELECT relname FROM pg_class WHERE oid = classid) AS class,  
        (SELECT typname FROM pg_type WHERE oid = obj) AS type,  
        (SELECT relname FROM pg_class WHERE oid = obj) AS class,  
        (SELECT relkind FROM pg_class where oid = obj::regclass) AS kind,  
        (SELECT adsrc FROM pg_attrdef WHERE oid = obj) AS attrdef,  
        (SELECT conname FROM pg_constraint WHERE oid = obj) AS constraint  
FROM dep  
ORDER BY obj;
<table>
<thead>
<tr>
<th>class</th>
<th>type</th>
<th>class</th>
<th>kind</th>
<th>attrdef</th>
<th>constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>pg_class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_type</td>
<td>_deptest</td>
<td></td>
<td></td>
<td></td>
<td>deptest_pkey</td>
</tr>
<tr>
<td>pg_type</td>
<td>deptest</td>
<td></td>
<td></td>
<td></td>
<td>deptest_pkey</td>
</tr>
<tr>
<td>pg_class</td>
<td></td>
<td>deptest_pkey</td>
<td>i</td>
<td></td>
<td>deptest_pkey</td>
</tr>
</tbody>
</table>
ALTER TABLE deptest ADD COLUMN x2 SERIAL;
NOTICE: ALTER TABLE will create implicit sequence "deptest_x2_seq" for serial column "deptest.x2"
WITH RECURSIVE dep (classid, obj) AS (  
  SELECT (SELECT oid FROM pg_class WHERE relname = 'pg_class'),  
         oid  
  FROM pg_class  
  WHERE relname = 'deptest'  
  UNION ALL  
  SELECT pg_depend.classid, objid  
  FROM pg_depend JOIN dep ON (refobjid = dep.obj)  
  )  
SELECT (SELECT relname FROM pg_class WHERE oid = classid) AS class,  
        (SELECT typname FROM pg_type WHERE oid = obj) AS type,  
        (SELECT relname FROM pg_class WHERE oid = obj) AS class,  
        (SELECT relkind FROM pg_class where oid = obj::regclass) AS kind,  
        (SELECT adsrc FROM pg_attrdef WHERE oid = obj) AS attrdef  
FROM dep  
ORDER BY obj;
### Output

<table>
<thead>
<tr>
<th>class</th>
<th>type</th>
<th>class</th>
<th>kind</th>
<th>attrdef</th>
</tr>
</thead>
<tbody>
<tr>
<td>pg_class</td>
<td>_deptest</td>
<td>deptest</td>
<td>r</td>
<td></td>
</tr>
<tr>
<td>pg_type</td>
<td>_deptest</td>
<td>deptest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_class</td>
<td>deptest</td>
<td>deptest_pkey</td>
<td>i</td>
<td></td>
</tr>
<tr>
<td>pg_constraint</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_class</td>
<td>deptest_x2_seq</td>
<td>deptest_x2_seq</td>
<td>S</td>
<td>nextval('deptest_x2_seq'::regclass)</td>
</tr>
<tr>
<td>pg_type</td>
<td>deptest_x2_seq</td>
<td></td>
<td></td>
<td>nextval('deptest_x2_seq'::regclass)</td>
</tr>
<tr>
<td>pg_attrdef</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_attrdef</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
WITH RECURSIVE dep (level, tree, classid, obj) AS (  
  SELECT 0, array_append(null, oid)::oid[],
          (SELECT oid FROM pg_class WHERE relname = 'pg_class'),
          oid
  FROM pg_class
  WHERE relname = 'deptest'

  UNION ALL

  SELECT level + 1, array_append(tree, objid),
          pg_depend.classid, objid
  FROM pg_depend JOIN dep ON (refobjid = dep.obj)
)

SELECT tree,
  (SELECT relname FROM pg_class WHERE oid = classid) AS class,
  (SELECT typname FROM pg_type WHERE oid = obj) AS type,
  (SELECT relname FROM pg_class WHERE oid = obj) AS class,
  (SELECT relkind FROM pg_class where oid = obj::regclass) AS kind
-- column removed to reduce output width

FROM dep
ORDER BY tree, obj;
<table>
<thead>
<tr>
<th>tree</th>
<th>class</th>
<th>type</th>
<th>class</th>
<th>kind</th>
</tr>
</thead>
<tbody>
<tr>
<td>{16458}</td>
<td>pg_class</td>
<td></td>
<td>deptest</td>
<td>r</td>
</tr>
<tr>
<td>{16458,16460}</td>
<td>pg_type</td>
<td>deptest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>{16458,16460,16459}</td>
<td>pg_type</td>
<td>_deptest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>{16458,16462}</td>
<td>pg_constraint</td>
<td></td>
<td>deptest_pkey</td>
<td>i</td>
</tr>
<tr>
<td>{16458,16462,16461}</td>
<td>pg_class</td>
<td>deptest_x2_seq</td>
<td></td>
<td>S</td>
</tr>
<tr>
<td>{16458,16463}</td>
<td>pg_class</td>
<td></td>
<td>deptest_x2_seq</td>
<td></td>
</tr>
<tr>
<td>{16458,16463,16464}</td>
<td>pg_type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>{16458,16463,16465}</td>
<td>pg_attrdef</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>{16458,16465}</td>
<td>pg_attrdef</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Writable CTEs

https://www.flickr.com/photos/dmelchordiaz/
Writable CTEs

- Allow data-modification commands (INSERT/UPDATE/DELETE) in WITH clauses
  - These commands can use RETURNING to pass data up to the containing query.
- Allow WITH clauses to be attached to INSERT, UPDATE, DELETE statements
CREATE TEMPORARY TABLE retdemo (x NUMERIC);

INSERT INTO retdemo VALUES (random()), (random()), (random()) RETURNING x;

<table>
<thead>
<tr>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00761545216664672</td>
</tr>
<tr>
<td>0.85416117589920831</td>
</tr>
<tr>
<td>0.10137318633496895</td>
</tr>
</tbody>
</table>

WITH source AS (  
  INSERT INTO retdemo  
  VALUES (random()), (random()), (random()) RETURNING x  
  )  
SELECT AVG(x) FROM source;

<table>
<thead>
<tr>
<th>avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.46403147140517833</td>
</tr>
</tbody>
</table>
Use **INSERT, UPDATE, DELETE** in **WITH** Clauses

WITH source AS (
    DELETE FROM retdemo RETURNING x
)
SELECT MAX(x) FROM source;

max
---------------------
0.93468171451240821
CREATE TEMPORARY TABLE retdemo2 (x NUMERIC);

INSERT INTO retdemo2 VALUES (random()), (random()), (random());

WITH source (average) AS ( 
    SELECT AVG(x) FROM retdemo2
)
DELETE FROM retdemo2 USING source 
WHERE retdemo2.x < source.average;

SELECT * FROM retdemo2;
  x
-------------------------------
  0.777186767663807
WITH RECURSIVE source (part_no) AS (  
    SELECT 2  
    UNION ALL  
    SELECT part.part_no  
    FROM source JOIN part ON (source.part_no = part.parent_part_no)  
)  
DELETE FROM part  
USING source  
WHERE source.part_no = part.part_no;
CREATE TEMPORARY TABLE retdemo3 (x NUMERIC);

INSERT INTO retdemo3 VALUES (random()), (random()), (random());

WITH source (average) AS (SELECT AVG(x) FROM retdemo3),
    source2 AS (DELETE FROM retdemo3 USING source WHERE retdemo3.x < source.average RETURNING x)

SELECT * FROM source2;

---

0.185174203012139
0.209731927141547
CREATE TEMPORARY TABLE orders (order_id SERIAL, name text);

CREATE TEMPORARY TABLE items (order_id INTEGER, part_id SERIAL, name text);

WITH source (order_id) AS (  
    INSERT INTO orders VALUES (DEFAULT, 'my order') RETURNING order_id  
)  
INSERT INTO items (order_id, name) SELECT order_id, 'my part' FROM source;

WITH source (order_id) AS (  
    DELETE FROM orders WHERE name = 'my order' RETURNING order_id  
)  
DELETE FROM items USING source WHERE source.order_id = items.order_id;
CREATE TEMPORARY TABLE old_orders (order_id INTEGER);

WITH source (order_id) AS (  
    DELETE FROM orders WHERE name = 'my order' RETURNING order_id  
), source2 AS (  
    DELETE FROM items USING source WHERE source.order_id = items.order_id  
)  
INSERT INTO old_orders SELECT order_id FROM source;
6. Why Use CTEs

- Allows imperative processing in SQL
- Merges multiple SQL queries and their connecting application logic into a single, unified SQL query
- Improves performance by issuing fewer queries
  - reduces transmission overhead, unless server-side functions are being used
  - reduces parsing/optimizing overhead, unless prepared statements are being used
- Uses the same row visibility snapshot for the entire query, rather than requiring serializable isolation mode
- Possible optimization barrier after each CTE
  - necessary for recursion and writable CTEs
  - can hurt performance when a join query is changed to use CTEs
  - pre-Postgres 12, CTEs are always an optimization barrier
  - Postgres 12 and later, a barrier only when useful
    - can be forced by keyword MATERIALIZED
Conclusion

http://momjian.us/presentations

https://www.flickr.com/photos/theophilusphotography/