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

1. Imperative vs. declarative
2. Syntax
3. Recursive CTEs
4. Examples
5. Writable CTEs
6. Why use CTEs
1. Imperative vs. Declarative

https://www.flickr.com/photos/visit_cape_may/
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
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.
BASIC:
10 PRINT "Hello"
20 GOTO 10

C:
while (1)
    printf("Hello\n");

Perl:
print("Hello\n") while (1);
Declarative

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
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;

<table>
<thead>
<tr>
<th>?column?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

The CTE created a `source` table that was referenced by the outer SELECT.

All queries in this presentation can be downloaded from https://momjian.us/main/writings/pgsql/cte.sql.
WITH source AS ( 
    SELECT 1 AS col1
) 
SELECT * FROM source;

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>col1</td>
<td>1</td>
</tr>
</tbody>
</table>

The CTE returned column is `source.col1`. 
WITH source (col1) AS ( 
    SELECT 1 
) 
SELECT * FROM source; 

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

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

<table>
<thead>
<tr>
<th>col3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

The CTE column starts as `col1`, is renamed in the `WITH` clause as `col2`, and the outer `SELECT` renames it to `col3`. 
WITH source AS (
    SELECT 1, 2
)
SELECT * FROM source;

| ?column? | ?column? |
|----------+----------|
| 1        | 2        |
SELECT 1
UNION
SELECT 1;
?column?
---------
  1

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

| column? | column? |
|---------+---------|
| 1       | 2       |
| 3       | 4       |
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;

<table>
<thead>
<tr>
<th>lanname</th>
<th>rolname</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>postgres</td>
</tr>
<tr>
<td>internal</td>
<td>postgres</td>
</tr>
<tr>
<td>plpgsql</td>
<td>postgres</td>
</tr>
<tr>
<td>sql</td>
<td>postgres</td>
</tr>
<tr>
<td>c</td>
<td></td>
</tr>
</tbody>
</table>
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;  
<table>
<thead>
<tr>
<th>relname</th>
<th>attname</th>
</tr>
</thead>
<tbody>
<tr>
<td>pg_aggregate</td>
<td>aggfinafnn</td>
</tr>
<tr>
<td>pg_aggregate</td>
<td>aggfnoid</td>
</tr>
<tr>
<td>pg_aggregate</td>
<td>aggininitval</td>
</tr>
<tr>
<td>pg_aggregate</td>
<td>aggsortop</td>
</tr>
<tr>
<td>pg_aggregate</td>
<td>aggtransfn</td>
</tr>
</tbody>
</table>
Imperative Control With CASE

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;  
?column?  
----------  
   1  

This does not loop because source is not mentioned in the CTE.
This Is an Infinite Loop

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
";
    f($arg + 1) if ($arg < 10);
}
f(1);
Perl Recursion Using an Array

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;
| counter | product |
|---------+---------|
| 1 | 1 |
| 2 | 2 |
| 3 | 6 |
| 4 | 24 |
| 5 | 120 |
| 6 | 720 |
| 7 | 5040 |
| 8 | 40320 |
| 9 | 362880 |
| 10 | 3628800 |
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; 

| counter | product |
|---------+---------|
| 10      | 3628800 |
Ten Factorial in 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;
Output

str
----------
a
aa
aaa
aaaa
aaaaa
aaaaaa
aaaaaaa
aaaaaaaa
aaaaaaaaa
aaaaaaaaaa
aaaaaaaaaaa
aaaaaaaaaaaa
WITH RECURSIVE source (str) AS (  
    SELECT 'a'
    UNION ALL
    SELECT str || chr(ascii(right(str, 1)) + 1)
    FROM source
    WHERE length(str) < 10
)
SELECT * FROM source;
Output

str
--------
 a
 ab
 abc
 abcd
 abcde
 abcdef
 abcddefg
 abcddefgh
 abcddefghi
 abcddefghij
WITH RECURSIVE source (counter) AS ( 
    SELECT -10 
    UNION ALL 
    SELECT counter + 1 
    FROM source 
    WHERE counter < 10 
)

SELECT repeat(' ', 5 - abs(counter) / 2) || 
     '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
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?

--------------------------------------------
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
X X
X X
X X
XX
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;
<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>
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;
<table>
<thead>
<tr>
<th>counter</th>
<th>factor</th>
<th>is_factor</th>
</tr>
</thead>
<tbody>
<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>7</td>
<td>1</td>
<td>t</td>
</tr>
</tbody>
</table>
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 
    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;
<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;
<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>5</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 WHERE is_factor;
| counter | factor | is_factor |
|---------+--------+-----------|
| 2       | 33     | t         |
| 3       | 11     | t         |
| 11      | 1      | t         |
Optimized Prime Factors of 66 in Perl

```perl
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;

<table>
<thead>
<tr>
<th>part_no</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>

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;  

part_tree  
-----------  
+2  
+--21  
+--22  
+--23  
+-----221  
+-----222  
+-----231
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;  

| 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  
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 pg_get_expr(adbin, classid) 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>deptest</td>
<td>r</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 pg_get_expr(adbin, classid) 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>
ADD A PRIMARY KEY

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 pg_get_expr(adbin, classid) 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>deptest</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_type</td>
<td>_deptest</td>
<td></td>
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<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_class</td>
<td></td>
<td>deptest_pkey</td>
<td>i</td>
<td></td>
<td>deptest_pkey</td>
</tr>
<tr>
<td>pg_constraint</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></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'),  
ioid  
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 pg_get_expr(adbin, classid) FROM pg_attrdef WHERE oid = obj) AS attrdef  
-- column removed to reduce output width  
FROM dep  
ORDER BY obj;
<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></td>
<td>deptest</td>
<td>r</td>
<td></td>
</tr>
<tr>
<td>pg_type</td>
<td>_deptest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_type</td>
<td>deptest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_class</td>
<td></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></td>
<td>deptest_x2_seq</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>pg_type</td>
<td>deptest_x2_seq</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pg_attrdef</td>
<td></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>nextval('deptest_x2_seq'::regclass)</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 pg_get_expr(adbin, classid) FROM pg_attrdef WHERE oid = obj) AS attrdef  
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></td>
<td></td>
</tr>
<tr>
<td>{16458,16460}</td>
<td>pg_type</td>
<td>deptest</td>
<td></td>
<td>r</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></td>
<td></td>
</tr>
<tr>
<td>{16458,16462,16461}</td>
<td>pg_class</td>
<td></td>
<td>deptest_pkey</td>
<td>i</td>
</tr>
<tr>
<td>{16458,16463}</td>
<td>pg_class</td>
<td></td>
<td>deptest_x2_seq</td>
<td>S</td>
</tr>
<tr>
<td>{16458,16463,16464}</td>
<td>pg_type</td>
<td>deptest_x2_seq</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;

---------------------
0.00761545216664672
0.85416117589920831
0.10137318633496895

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

---------------------
0.46403147140517833
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;

<table>
<thead>
<tr>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.185174203012139</td>
</tr>
<tr>
<td>0.209731927141547</td>
</tr>
</tbody>
</table>
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, CURRENT_USER, CURRENT_TIMESTAMP 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 repeatable read 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

https://momjian.us/presentations

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