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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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.
**Imperative**

**BASIC:**

10 PRINT "Hello"
20 GOTO 10

**C:**

```c
while (1) {
    printf("Hello\n");
}
```

**Perl:**

```perl
print("Hello\n") while (1);
```
Declarative

SQL:

```
SELECT 'Hello'
UNION ALL
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/
A Simple CTE

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

1

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.
Let’s Name the Returned CTE Column

WITH source AS (  
    SELECT 1 AS col1  
  )  
SELECT * FROM source;  
    col1     
------     
    1

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

WITH source (col1) AS (  
    SELECT 1  
)  
SELECT * FROM source;  
col1  
-----  
   1
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*.
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;

| 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>
CTE Can Be Processed More than Once

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;  
    relname | attname  
--------------------------+------------  
 pg_aggregate | aggfinafn  
 pg_aggregate | aggfoid  
 pg_aggregate | agginival  
 pg_aggregate | aggsortop  
 pg_aggregate | aggtransfn
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 'negative'
FROM tab;
3. Recursive CTEs
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
";
}
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>
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
aaaaaa
aaaaaa
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;
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' ||
    repeat(' ', abs(counter)) ||
    'X'
FROM source;
<table>
<thead>
<tr>
<th>?column?</th>
</tr>
</thead>
<tbody>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
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<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
<tr>
<td>X   X</td>
</tr>
</tbody>
</table>
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
  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

?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
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)/5)) ||
  'X' ||
  repeat(' ', 2 * (20 - int4(pow(counter, 2)/5))) ||
  'X'
FROM source;
The prime factors of $X$ are the prime numbers that must be multiplied to equal a $X$, 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;
## Output

<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;
| counter | factor | is_factor |
|---------+--------+-----------|
| 2       | 66     | f         |
| 2       | 33     | t         |
| 3       | 33     | f         |
| 3       | 11     | t         |
| 4       | 11     | f         |
| 5       | 11     | f         |
| 6       | 11     | f         |
| 7       | 11     | f         |
| 8       | 11     | f         |
| 9       | 11     | f         |
| 10      | 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 
END, 
CASE 
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;
<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;
Recursive Table Processing: Setup

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;

<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, 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 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>
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>
<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_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'),
            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
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>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></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></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

[Image: https://www.flickr.com/photos/dmelchordiaz/86]
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
Use `INSERT`, `UPDATE`, `DELETE` in `WITH` Clauses

```
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
```

88/96
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;

  x
-------------------
  0.185174203012139
  0.209731927141547

92/96
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, delete_user TEXT, delete_time TIMESTAMPTZ);

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
    - see https://www.postgresql.eu/events/pgconfeu2022/sessions/session/3902/slides/354/CTEsAndTheirMaterialization-DivyaSharma.pdf
Conclusion

https://momjian.us/presentations

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