Windowing Functions

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What are Windowing Functions?
What are the Windowing Functions?

• Similar to classical aggregates but does more!
• Provides access to set of rows from the current row
• Introduced SQL:2003 and more detail in SQL:2008
    • 4.14.9 Window tables
    • 4.15.3 Window functions
    • 6.10 <window function>
    • 7.8 <window clause>
• Supported by Oracle, SQL Server, Sybase and DB2
  – No open source RDBMS so far except PostgreSQL (Firebird trying)
• Used in OLAP mainly but also useful in OLTP
  – Analysis and reporting by rankings, cumulative aggregates
How they work and what you get
How they work and what do you get

• Windowed table
  – Operates on a windowed table
  – Returns a value for each row
  – Returned value is calculated from the rows in the window
How they work and what do you get

• You can use...
  – New window functions
  – Existing aggregate functions
  – User-defined window functions
  – User-defined aggregate functions
How they work and what do you get

• Completely new concept!
  – With Windowing Functions, you can reach outside the current row
How they work and what you get

[Aggregates]  

SELECT key, SUM(val) FROM tbl GROUP BY key;
How they work and what you get

[Windowing Functions]  SELECT key, SUM(val) OVER (PARTITION BY key) FROM tbl;
How they work and what you get

Who is the highest paid relatively compared with the department average?

<table>
<thead>
<tr>
<th>depname</th>
<th>empno</th>
<th>salary</th>
</tr>
</thead>
<tbody>
<tr>
<td>develop</td>
<td>10</td>
<td>5200</td>
</tr>
<tr>
<td>sales</td>
<td>1</td>
<td>5000</td>
</tr>
<tr>
<td>personnel</td>
<td>5</td>
<td>3500</td>
</tr>
<tr>
<td>sales</td>
<td>4</td>
<td>4800</td>
</tr>
<tr>
<td>sales</td>
<td>6</td>
<td>550</td>
</tr>
<tr>
<td>personnel</td>
<td>2</td>
<td>3900</td>
</tr>
<tr>
<td>develop</td>
<td>7</td>
<td>4200</td>
</tr>
<tr>
<td>develop</td>
<td>9</td>
<td>4500</td>
</tr>
<tr>
<td>sales</td>
<td>3</td>
<td>4800</td>
</tr>
<tr>
<td>develop</td>
<td>8</td>
<td>6000</td>
</tr>
<tr>
<td>develop</td>
<td>11</td>
<td>5200</td>
</tr>
</tbody>
</table>
How they work and what you get

```sql
SELECT depname, empno, salary, avg(salary) OVER (PARTITION BY depname)::int,
       salary - avg(salary) OVER (PARTITION BY depname)::int AS diff
FROM empsalary ORDER BY diff DESC
```

<table>
<thead>
<tr>
<th>depname</th>
<th>empno</th>
<th>salary</th>
<th>avg</th>
<th>diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>develop</td>
<td>8</td>
<td>6000</td>
<td>5020</td>
<td>980</td>
</tr>
<tr>
<td>sales</td>
<td>6</td>
<td>5500</td>
<td>5025</td>
<td>475</td>
</tr>
<tr>
<td>personnel</td>
<td>2</td>
<td>3900</td>
<td>3700</td>
<td>200</td>
</tr>
<tr>
<td>develop</td>
<td>11</td>
<td>5200</td>
<td>5020</td>
<td>180</td>
</tr>
<tr>
<td>develop</td>
<td>10</td>
<td>5200</td>
<td>5020</td>
<td>180</td>
</tr>
<tr>
<td>sales</td>
<td>1</td>
<td>5000</td>
<td>5025</td>
<td>-25</td>
</tr>
<tr>
<td>personnel</td>
<td>5</td>
<td>3500</td>
<td>3700</td>
<td>-200</td>
</tr>
<tr>
<td>sales</td>
<td>4</td>
<td>4800</td>
<td>5025</td>
<td>-225</td>
</tr>
<tr>
<td>sales</td>
<td>3</td>
<td>4800</td>
<td>5025</td>
<td>-225</td>
</tr>
<tr>
<td>develop</td>
<td>9</td>
<td>4500</td>
<td>5020</td>
<td>-520</td>
</tr>
<tr>
<td>develop</td>
<td>7</td>
<td>4200</td>
<td>5020</td>
<td>-820</td>
</tr>
</tbody>
</table>
Anatomy of a Window

• Represents set of rows abstractly as:
  • A partition
    – Specified by PARTITION BY clause
    – Never moves
    – Can contain:
  • A frame
    – Specified by ORDER BY clause and frame clause
    – Defined in a partition
    – Moves within a partition
    – Never goes across two partitions
• Some functions take values from a partition. Others take them from a frame.
A partition

- Specified by PARTITION BY clause in OVER()
- Allows to subdivide the table, much like GROUP BY clause
- Without a PARTITION BY clause, the whole table is in a single partition
A frame

- Specified by ORDER BY clause and frame clause in OVER()
- Allows to tell how far the set is applied
- Also defines ordering of the set
- Without order and frame clauses, the whole of partition is a single frame

```
func (args)

OVER (
  partition-clause
  order-clause
  frame-clause
)
```

```
ORDER BY expr [ASC|DESC] [NULLS FIRST|LAST], ...

(ROWS|RANGE) BETWEEN UNBOUNDED (PRECEDING|FOLLOWING) AND CURRENT ROW
```
The WINDOW clause

• You can specify common window definitions in one place and name it, for convenience
• You can use the window at the same query level

```
SELECT   target_list, … wfunc() OVER w
FROM  table_list, …
WHERE  qual_list, ….
GROUP BY  groupkey_list, ….
HAVING groupqual_list, …
```

```
WINDOW w AS ( partition-clause order-clause frame-clause )
```
Built-in Windowing Functions
List of built-in Windowing Functions

- `row_number()`
- `rank()`
- `dense_rank()`
- `percent_rank()`
- `cume_dist()`
- `ntile()`
- `lag()`
- `lead()`
- `first_value()`
- `last_value()`
- `nth_value()`
row_number()

- Returns number of the current row

```sql
SELECT val, row_number() OVER (ORDER BY val DESC) FROM tbl;
```

<table>
<thead>
<tr>
<th>val</th>
<th>row_number()</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: row_number() always incremented values independent of frame.
**rank()**

- Returns rank of the current row with gap

```sql
SELECT val, rank() OVER (ORDER BY val DESC) FROM tbl;
```

<table>
<thead>
<tr>
<th>val</th>
<th>rank()</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: `rank() OVER(*empty*)` returns 1 for all rows, since all rows are peers to each other.
dense_rank()

- Returns rank of the current row **without** gap

SELECT val, dense_rank() OVER (ORDER BY val DESC) FROM tbl;

<table>
<thead>
<tr>
<th>val</th>
<th>dense_rank()</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: dense_rank() OVER(*empty*) returns 1 for all rows, since all rows are peers to each other.
percent_rank()

- Returns relative rank; \((\text{rank()} - 1) / (\text{total row} - 1)\)

```
SELECT val, percent_rank() OVER (ORDER BY val DESC) FROM tbl;
```

<table>
<thead>
<tr>
<th>val</th>
<th>percent_rank()</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.6666666666666667</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Values are always between 0 and 1 inclusive.

Note: `percent_rank()` OVER(*empty*) returns 0 for all rows, since all rows are peers to each other.
cume_dist()

- Returns relative rank; (# of preced. or peers) / (total row)

```
SELECT val, cume_dist() OVER (ORDER BY val DESC) FROM tbl;
```

<table>
<thead>
<tr>
<th>val</th>
<th>cume_dist()</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The result can be emulated by
```
"count(*) OVER (ORDER BY val DESC) / count(*) OVER ()"
```

Note: cume_dist() OVER(*empty*) returns 1 for all rows, since all rows are peers to each other
ntile()  

- Returns dividing bucket number

SELECT val, ntile(3) OVER (ORDER BY val DESC) FROM tbl;

<table>
<thead>
<tr>
<th>val</th>
<th>ntile(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

The results are the divided positions, but if there’s remainder add row from the head.

Note: ntile() OVER (*empty*) returns same values as above, since ntile() doesn’t care the frame but works against the partition.

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### lag()

- Returns value of row above

```sql
SELECT val, lag(val) OVER (ORDER BY val DESC) FROM tbl;
```

<table>
<thead>
<tr>
<th>val</th>
<th>lag(val)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>NULL</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: lag() only acts on a partition.
lead()

- Returns value of the row below

```
SELECT val, lead(val) OVER (ORDER BY val DESC) FROM tbl;
```

<table>
<thead>
<tr>
<th>val</th>
<th>lead(val)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>NULL</td>
</tr>
</tbody>
</table>

Note: lead() acts against a partition.
first_value()

- Returns the first value of the frame

```
SELECT val, first_value(val) OVER (ORDER BY val DESC) FROM tbl;
```

<table>
<thead>
<tr>
<th>val</th>
<th>first_value(val)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>
last_value()

- Returns the last value of the frame

```sql
SELECT val, last_value(val) OVER
(ORDER BY val DESC ROWS BETWEEN UNBOUNDED PRECEDING
AND UNBOUNDED FOLLOWING) FROM tbl;
```

<table>
<thead>
<tr>
<th>val</th>
<th>last_value(val)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: frame clause is necessary since you have a frame between the first row and the current row by only the order clause
nth_value()

- Returns the n-th value of the frame

SELECT val, nth_value(val, val) OVER
  (ORDER BY val DESC ROWS BETWEEN UNBOUNDED PRECEDING AND UNBOUNDED FOLLOWING) FROM tbl;

<table>
<thead>
<tr>
<th>val</th>
<th>nth_value(val, val)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>NULL</td>
</tr>
<tr>
<td>5</td>
<td>NULL</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: frame clause is necessary since you have a frame between the first row and the current row by only the order clause.
aggregates(all peers)

- Returns the same values along the frame

```sql
SELECT val, sum(val) OVER () FROM tbl;
```

<table>
<thead>
<tr>
<th>val</th>
<th>sum(val)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
</tr>
</tbody>
</table>

Note: all rows are the peers to each other
cumulative aggregates

- Returns different values along the frame

```
SELECT val, sum(val) OVER (ORDER BY val DESC) FROM tbl;
```

<table>
<thead>
<tr>
<th>val</th>
<th>sum(val)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
</tr>
</tbody>
</table>

Note: row#1 and row#2 return the same value since they are the peers. The result of row#3 is sum(val of row#1...#3)
Inside the Implementation
Where are they?

• Windowing Functions are identified by a flag in pg_proc, which means they are very similar to plain functions
  – pg_proc.proiswindow : boolean

• All the aggregates including user–defined ones in any language can be called in WindowAgg, too
  – Your old code gets new behaviour!

• src/include/catalog/pg_proc.h
  – pg_proc catalog definitions

• src/backend/utils/adt/windowfuncs.c
  – implementations of built–in window functions
Added relevant nodes

- **WindowFunc**
  - primitive node for function itself “wfunc(avg1, ...)”

- **WindowDef**
  - parse node for window definition “over (partition by ... order by ...)”

- **WindowClause**
  - parse node for window clause “window (partition by ... order by ...) as w”

- **WindowAgg**
  - plan node for window aggregate

- **WindowAggState**
  - executor node for window aggregate
Hacking the planner

```sql
SELECT depname, empno, salary,
  avg(salary) over (partition by depname) AS a,
  rank() over (partition by depname order by salary desc) AS r
FROM empsalary ORDER BY r
```

Sort (cost=215.75..218.35 rows=1040 width=44)
  Output: depname, empno, salary, (avg(salary) OVER (?)), (rank() OVER (?))
  Sort Key: (rank() OVER (?))
  -> WindowAgg (cost=142.83..163.63 rows=1040 width=44)
    Output: depname, empno, salary, (avg(salary) OVER (?)), rank() OVER (?)
    -> Sort (cost=142.83..145.43 rows=1040 width=44)
      Output: depname, empno, salary, (avg(salary) OVER (?))
      Sort Key: depname, salary
    -> WindowAgg (cost=72.52..90.72 rows=1040 width=44)
      Output: depname, empno, salary, avg(salary) OVER (?)
      -> Sort (cost=72.52..75.12 rows=1040 width=44)
        Output: depname, empno, salary
        Sort Key: depname
      -> Seq Scan on empsalary (cost=0.00..20.40 rows=1040 width=44)
        Output: depname, empno, salary
```
Hacking the planner

Final output

TargetEntry1:depname
TargetEntry2:empno
TargetEntry3:salary
TargetEntry4:avg
TargetEntry5:rank
Hacking the planner

Final output

TargetEntry1:depname
TargetEntry2:empno
TargetEntry3:salary
TargetEntry4:avg
TargetEntry5:rank

SeqScan

Var1:depname
Var2:empno
Var3:salary
Hacking the planner

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Final output

TargetEntry1: depname
TargetEntry2: empno
TargetEntry3: salary
TargetEntry4: avg
TargetEntry5: rank

WindowAgg1
Var1: depname
Var2: empno
Var3: salary
WindowFunc1: avg

Sort1
SeqScan
Var1: depname
Var2: empno
Var3: salary
Hacking the planner

• We could optimize it by relocating WindowAgg

SELECT depname, empno, salary,
    rank() over (partition by depname order by salary desc) AS r,
    avg(salary) over (partition by depname) AS a
FROM empsalary ORDER BY r

Sort (cost=161.03..163.63 rows=1040 width=44)
  Output: depname, empno, salary, (rank() OVER (?)), (avg(salary) OVER (?))
Sort Key: (rank() OVER (?))
  -> WindowAgg (cost=72.52..108.92 rows=1040 width=44)
    Output: depname, empno, salary, (rank() OVER (?)), avg(salary) OVER (?)
    -> WindowAgg (cost=72.52..93.32 rows=1040 width=44)
    Output: depname, empno, salary, rank() OVER (?)
    -> Sort (cost=72.52..75.12 rows=1040 width=44)
      Output: depname, empno, salary
      Sort Key: depname, salary
      -> Seq Scan on empsalary (cost=0.00..20.40 rows=1040 width=44)
        Output: depname, empno, salary
How the executor creates a window

Normal Scan

Table

row#1
row#2
row#3
row#4

Destination

Values are never shared among returned rows
How the executor creates a window

Table

WindowAgg

Buffering rows in the Window Object, so the functions can fetch values from another row.

This kills performance if the Window Object holds millions of rows.

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How the executor creates a window

If the rest of rows don’t need buffered rows any more, trim the Tuplestore from its head to “mark pos”
How the Windowing Functions work

- Functions workflow is very similar to plain functions
- Each function has its own seek position

```c
WindowAgg calls the wfunc1()

wfunc1(fcinfo){
  WindowObject winobj = PG_WINDOW_OBJECT();
  /* do something using winobj */
}

Return a value
```
How the Windowing Functions work

- What about aggregates?

Trans value is cached and reused after final function call.

-> BE CAREFUL of anything that will break if the final function is called more than once.

Write Your Own Windowing Function
Write your own Windowing Function

• NOT documented for now, but you can do it
• The normal argument API like PG_GETARG_XXX() does not work for window functions
• STRICT-ness is meaningless
• The function must use the V1 calling convention
• Get WindowObject using PG_WINDOW_OBJECT()
• Check window-ness by WindowObjectIsValid()
• Call APIs to fetch values
• More details in src/include/windowapi.h, see also:
  – src/executor/nodeWindowAgg.c
  – src/utils/adt/windowfuncs.c
• These may be changed in the future releases
Windowing Function APIs

- **PG_WINDOW_OBJECT(fcinfo)**
  - Retrieve WindowObject, which is an interface of the window, for this call.

- **WinGetPartitionLocalMemory(winobj, sz)**
  - Store its own memory. It is used in rank() to save the current rank, for example.

- **WinGetCurrentPosition(winobj)**
  - Get current position in the partition (not in the frame). Same as row_number()

- **WinGetPartitionRowCount(winobj)**
  - Count up how many rows in the partition. Used in ntile() for example.
Windowing Function APIs

- **WinSetMarkPosition**(winobj, markpos)
  - Give to winobj a hint that you don’t want rows preceding to markpos anymore

- **WinRowsArePeers**(winobj, pos1, pos2)
  - Rows at pos1 and at pos2 are peers? “Peers” means both rows have the same value in the meaning of ORDER BY columns
Windowing Function APIs

- **WinGetFuncArgInPartition**(winobj, argno, relpos, seektype, set_mark, isnull, isout)
  - Fetch argument from another row in the partition. “isout” will be set to true if “relpos” is out of range of the partition.

- **WinGetFuncArgInFrame**(winobj, argno, relpos, seektype, set_mark, isnull, isout)
  - Fetch argument from another row in the frame. “isout” will be set to true if “relpos” is out of range of the frame (may be within the partition.)

- **WinGetFuncArgCurrent**(winobj, argno, isnull)
  - Same as PG_GETARG_XXX(argno). Fetch argument from the current row.
Moving average example

- With standard SQL, you have to wait for extended frame clause support like ROWS n (PRECEDING|FOLLOWING) to calculate curve smoothing, but this sample does it now.
Future work
Future work for later versions

• More support for frame clause
  – ROWS n (PRECEDING|FOLLOWING)
  – RANGE val (PRECEDING|FOLLOWING)
  – EXCLUDE (CURRENT ROW|GROUP|TIES|NO OTHERS)
  – Not so difficult for window functions but integration with classical aggregates is hard

• Performance improvements
  – Reduce tuplestore overhead
  – Relocate WindowAgg node in the plan

• Support PLs for writing Windowing Functions
  – Let PLs call Windowing Function APIs
Finally…
Thanks all the hackers!!

- Simon Riggs
  - discussion over my first ugly and poor design
- Heikki Linnakangas
  - improvement of window object and its buffering strategy
- Tom Lane
  - code rework overall and deep reading in the SQL spec
- David Fetter
  - help miscellaneous things like git repository and this session
- David Rowley
  - many tests to catch early bugs, as well as spec investigations
- Takahiro Itagaki, Pavel Stehule, and All the Hackers
- I might have missed your name here, but really appreciate your help.