Non-Standard-Datenbanken und Data Mining

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Übersicht

- Semistrukturierte Datenbanken (JSON, XML) und Volltextsuche
- Information Retrieval
- Mehrdimensionale Indexstrukturen
- Cluster-Bildung
- Einbettungstechniken
- First-n-, Top-k-, und Skyline-Anfragen
- Probabilistische Datenbanken, Anfragebeantwortung, Top-k-Anfragen und Open-World-Annahme
- Probabilistische Modellierung, Bayes-Netze, Anfragebeantwortungsalgorithmen, Lernverfahren,
- Temporale Datenbanken und das relationale Modell,
- Probabilistische Temporale Datenbanken
- SQL: neue Entwicklungen (z.B. JSON-Strukturen und Arrays), Zeitreihen (z.B. TimeScaleDB)
- Stromdatenbanken, Prinzipien der Fenster-orientierten inkrementellen Verarbeitung
- Approximationstechniken für Stromdatenverarbeitung, Stream-Mining
- Probabilistische raum-zeitliche Datenbanken und Stromdatenverarbeitungsssysteme: Anfragen und Indexstrukturen, Raum-zeitliches Data Mining
- Von NoSQL- zu NewSQL-Datenbanken, CAP-Theorem, CALM-Theorem
- Blockchain-Datenbanken
- Analyse von Graphdaten

SQL Standard – Brief History

- SO/IEC 9075 Database Language SQL
  - SQL-86 – Transactions, Create, Read, Update, Delete
  - SQL-89 – Referential Integrity
  - SQL-92 – Internationalization, etc.
  - SQL:1999 – User Defined Types
  - SQL:2003 – XML
  - SQL:2008 – Expansions and corrections
  - SQL:2011 – Temporal
  - SQL:2016 – JSON, PTFs, RPR
  - SQL:2019 – MDA
- 30+ years of support and expansion of the standard

SQL:2016 New Features

- Support for Java Script Object Notation (JSON)
  - Store, query, and retrieve JSON
- Polymorphic table functions
  - Parameters and function return values can be tables whose shape is not known until query time
- Row pattern recognition
  - Regular Expressions across sequences of rows
- Additional functions (e.g., for analytics)
  - Trigonometric and logarithm functions
  - Concatenate strings over groups of rows
- Default values and names for arguments of SQL functions

Acknowledgements

- Parts of subsequent presentations are taken from

  J. Michels et al., The New and Improved SQL:2016 Standard,
  SIGMOD Record, Vol. 47, No. 2, pp. 51-60, **2018**

Support for Java Script Object Notation

ID	JCOL
111	{ "Name" : "John Smith", "address" : { "streetAddress": "21 2nd Street", "city": "New York", "state" : "NY", "postalCode" : 10021 }, "phoneNumber" : [{ "type" : "home", "number" : "212 555-1234" }, { "type" : "fax", "number" : "646 555-4567" }] }
222	{ "Name" : "Peter Walker", "address" : { "streetAddress": "111 Main Street", "city": "San Jose", "state" : "CA", "postalCode" : 95111 }, "phoneNumber" : [{ "type" : "home", "number" : "408 555-9876" }, { "type" : "office", "number" : "650 555-2468" }] }
333	{ "Name" : "James Lee" }

JSON Type

```
CREATE TABLE T (
  Id INTEGER PRIMARY KEY,
  Jcol CHARACTER VARYING ( 5000 )
          CHECK ( Jcol IS JSON ) )

SELECT * FROM T WHERE Jcol IS JSON
```

JSON Path Expressions

```
SELECT Id
FROM T
WHERE JSON_EXISTS ( Jcol,
        'strict $.address' )
```

Find 111 and 222 but not 333 (due to strict)

Extract scalars

```
SELECT Id, JSON_VALUE ( Jcol,
   'lax $.phoneNumber[0].number' )
   AS Firstphone
FROM T
```

Lax is default

Find 111, 222, and 333 with null (due to lax)

Support for Java Script Object Notation

ID	JCOL
111	{ "Name" : "John Smith", "address" : { "streetAddress": "21 2nd Street", "city": "New York", "state" : "NY", "postalCode" : 10021 }, "phoneNumber" : [{ "type" : "home", "number" : "212 555-1234" }, { "type" : "fax", "number" : "646 555-4567" }] }
222	{ "Name" : "Peter Walker", "address" : { "streetAddress": "111 Main Street", "city": "San Jose", "state" : "CA", "postalCode" : 95111 }, "phoneNumber" : [{ "type" : "home", "number" : "408 555-9876" }, { "type" : "office", "number" : "650 555-2468" }] }
333	{ "Name" : "James Lee" }

Filters

```
SELECT Id, JSON_VALUE ( Jcol,
   'lax $.phoneNumber
      ? ( @.type == "fax" ).number' )
    AS Fax
FROM T
```

Find 111, 222 with null, and 333 with null
Return type is string if not specified otherwise

Extract JSON fragments (objects, arrays, scalars)

```
SELECT Id, JSON_QUERY ( Jcol,
   'lax $.address' ) AS Address
FROM T
```

ID	ADDRESS
111	{ "streetAddress": "21 2nd Street", "city": "New York", "state" : "NY", "postalCode" : 10021 }
222	{ "streetAddress": "111 Main Street", "city": "San Jose", "state" : "CA", "postalCode" : 95111 }
333	

Support for Java Script Object Notation

ID	JCOL
111	{ "Name" : "John Smith", "address" : { "streetAddress": "21 2nd Street", "city": "New York", "state" : "NY", "postalCode" : 10021 }, "phoneNumber" : [{ "type" : "home", "number" : "212 555-1234" }, { "type" : "fax", "number" : "646 555-4567" }] }
222	{ "Name" : "Peter Walker", "address" : { "streetAddress": "111 Main Street", "city": "San Jose", "state" : "CA", "postalCode" : 95111 }, "phoneNumber" : [{ "type" : "home", "number" : "408 555-9876" }, { "type" : "office", "number" : "650 555-2468" }] }
333	{ "Name" : "James Lee" }

JSON to tables

```
SELECT T.Id, Jt.Name, Jt.Zip
FROM T,
  JSON_TABLE ( T.Jcol, 'lax $'
    COLUMNS (
      Name VARCHAR ( 30 )
           PATH 'lax $.Name'
      Zip  VARCHAR ( 5 ) PATH
           'lax $.address.postalCode'
      )
   ) AS Jt
```

ID	NAME	ZIP
111	John Smith	10021
222	Peter Walker	95111
333	James Lee	

Also used for unnesting (deeply) nested JSON structures or arrays

Support for Java Script Object Notation

ID	JCOL
111	{ "Name" : "John Smith", "address" : { "streetAddress": "21 2nd Street", "city": "New York", "state" : "NY", "postalCode" : 10021 }, "phoneNumber" : [{ "type" : "home", "number" : "212 555-1234" }, { "type" : "fax", "number" : "646 555-4567" }] }
222	{ "Name" : "Peter Walker", "address" : { "streetAddress": "111 Main Street", "city": "San Jose", "state" : "CA", "postalCode" : 95111 }, "phoneNumber" : [{ "type" : "home", "number" : "408 555-9876" }, { "type" : "office", "number" : "650 555-2468" }] }
333	{ "Name" : "James Lee" }

JSON to tables

```
SELECT T.Id, Jt.Name, Jt.Type,
       Jt.Number
FROM T,
  JSON_TABLE ( T.Jcol, 'lax $'
    COLUMNS
     ( Name VARCHAR ( 30 )
              PATH 'lax $.Name',
       NESTED PATH
            'lax $.phoneNumber[*]'
       COLUMNS
         ( Type VARCHAR ( 10 )
                PATH 'lax $.type',
           Number VARCHAR ( 12 )
                PATH 'lax $.number' )
     )
  ) AS Jt
```

ID	NAME	TYPE	NUMBER
111	John Smith	home	212 555-1234
111	John Smith	fax	646 555-4567
222	Peter Walker	home	408 555-9876
222	Peter Walker	office	650 555-2468
333	James Lee		

Support for Java Script Object Notation

ID	JCOL
111	{ "Name" : "John Smith", "address" : { "streetAddress": "21 2nd Street", "city": "New York", "state" : "NY", "postalCode" : 10021 }, "phoneNumber" : [{ "type" : "home", "number" : "212 555-1234" }, { "type" : "fax", "number" : "646 555-4567" }] }
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333	{ "Name" : "James Lee" }

Structural inspection

```
strict $.* ? ( @.type() == "array"
               && @.size() > 1 )
```

Tables to JSON objects

```
SELECT JSON_OBJECT
 ( KEY 'department' VALUE D.Name,
   KEY 'employees'
    VALUE JSON_ARRAYAGG
          ( JSON_OBJECT
            ( KEY 'employee'
              VALUE E.Name,
             KEY 'salary'
              VALUE E.Salary )
            ORDER BY E.Salary ASC )
 ) AS Department
FROM Departments D, Employees E
WHERE D.Dept_id = E.Dept_id
GROUP BY D.Name
```

DEPARTMENT
{ "department" : "Sales", "employees" : [{ "employee" : "James", "salary" : 7000 }, { "employee" : "Rachel", "salary" : 9000 }, { "employee" : "Logan", "salary" : 10000 }] }
…

Polymorphic Table Functions (PTFs)

- Reading a CSV file returns a table with structure unknown at compile time

```
SELECT *
FROM TABLE
    ( CSVreader (
          File => 'abc.csv',
          Floats => DESCRIPTOR
           ( "principal", "interest" )
          Dates => DESCRIPTOR
           ( "due_date" ) ) ) AS S
```

There must be column names „principal“ and „interest“ as well as a „due_date“ column

```
CREATE FUNCTION CSVreader (
      File VARCHAR(1000),
      Floats DESCRIPTOR DEFAULT NULL,
      Dates DESCRIPTOR DEFAULT NULL )
RETURNS TABLE
NOT DETERMINISTIC CONTAINS SQL
PRIVATE DATA ( FileHandle INTEGER )
DESCRIBE WITH PROCEDURE
         CSVreader_describe
START WITH PROCEDURE
         CSVreader_start
FULFILL WITH PROCEDURE
         CSVreader_fulfill
FINISH WITH PROCEDURE
         CSVreader_finish
```

Different results with same input parameters
Code supplied with SQL stored procedures

DESCRIBE: Determin row type
START: Allocate resources
FULFILL: Read a tuple
FULFILL: Deallocate resources

Polymorphic Table Functions (PTFs)

- User-defined joins

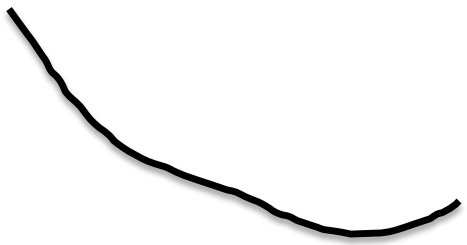
```
CREATE FUNCTION UDJoin
 ( T1 TABLE PASS THROUGH
            WITH SET SEMANTICS
            PRUNE WHEN EMPTY,
   T2 TABLE PASS THROUGH
            WITH SET SEMANTICS
            KEEP WHEN EMPTY
 ) RETURNS ONLY PASS THROUGH
```

```
SELECT E.*, D.*
FROM TABLE
     ( UDJoin (
           T1 => TABLE (Emp) AS E
                 PARTITION BY Deptno,
           T2 => TABLE (Dept) AS D
                 PARTITION BY Deptno
                 ORDER BY Tstamp ) )
```

- WITH SET SEMANTICS
  all rows of a partition to be processed on the same virtual processor (“partitionable“)
- PARTITION BY:
  Table partitioned on list of columns, to be processed on separate virtual processor each

Row Pattern Recognition

- Search an ordered partition of rows for matches to a regular expression
- RPR can be supported in either the FROM clause or the WINDOW clause



Symbol	Tradeday	Price
XYZ	2009-06-08	50
XYZ	2009-06-09	60
XYZ	2009-06-10	49
XYZ	2009-06-11	40
XYZ	2009-06-12	35
XYZ	2009-06-13	45
XYZ	2009-06-14	45

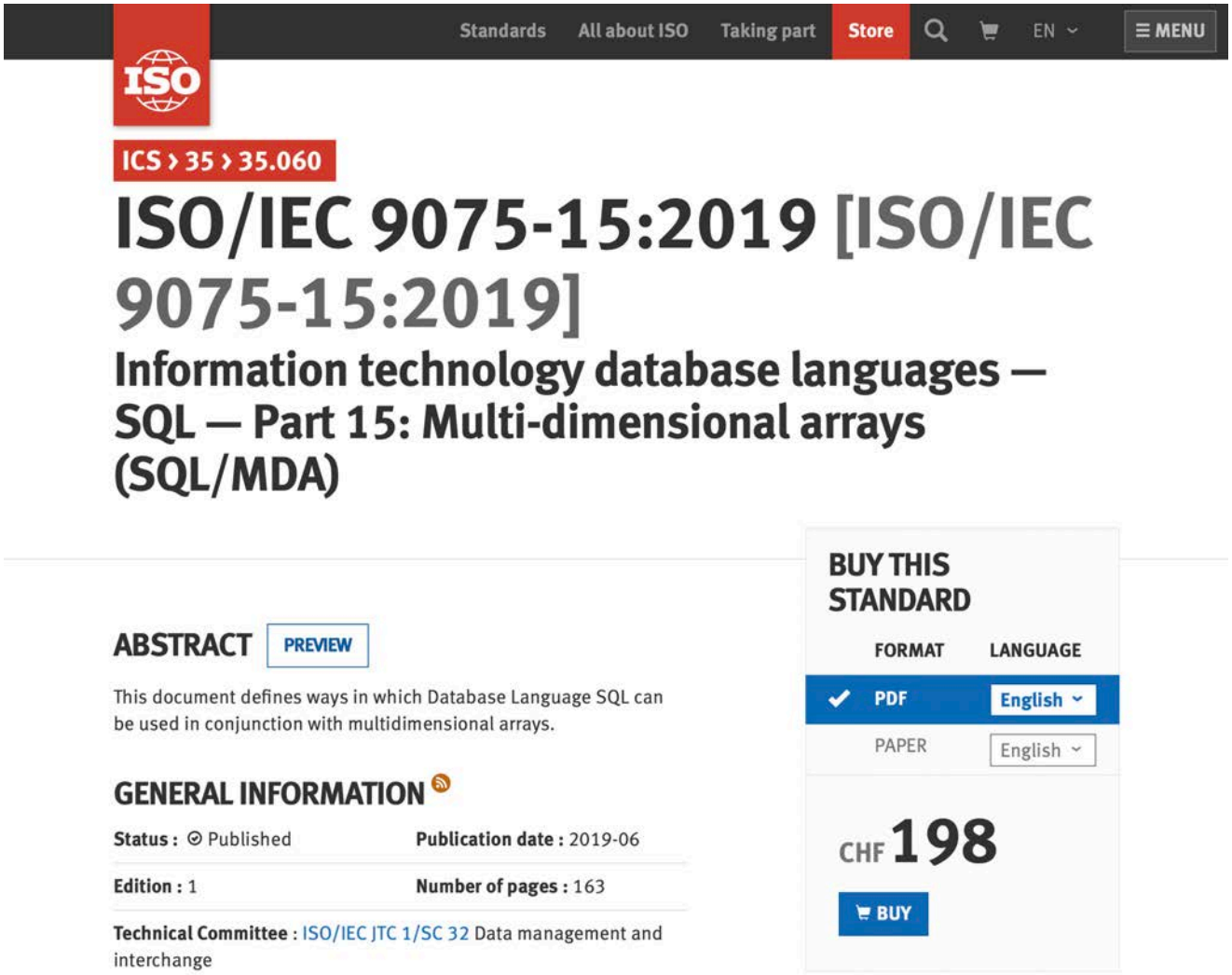
Symbol	Matchno	Startp	Bottomp	Endp	Avgp
XYZ	1	60	35	45	45.8

What's Next?

- SQL:2019: Multi Dimensional Arrays – SQL/MDA
  - Applications in natural sciences research (heat maps), geo applications (e.g., remote sensing image processing)
  - 1D-Arrays already in SQL:1999 (very limited ways to query and update)
  - Multidimensional arrays discussed for more than 20 years
  - Prominent example array databases:
    - Rasdaman (Peter Baumann)
    - SciDB (Michael Stonebraker)
- SQL:2020+: Property Graphs
  - Also discussed for about 20 years
    - Neo4j graph database (Cypher)
    - RDF (SPARQL)
- In the works: Streaming SQL
- Probabilistic modeling in SQL:2030?

It takes about 20-30 years from non-standard features to standard elements

SQL:2019 Part 15 ISO Standard

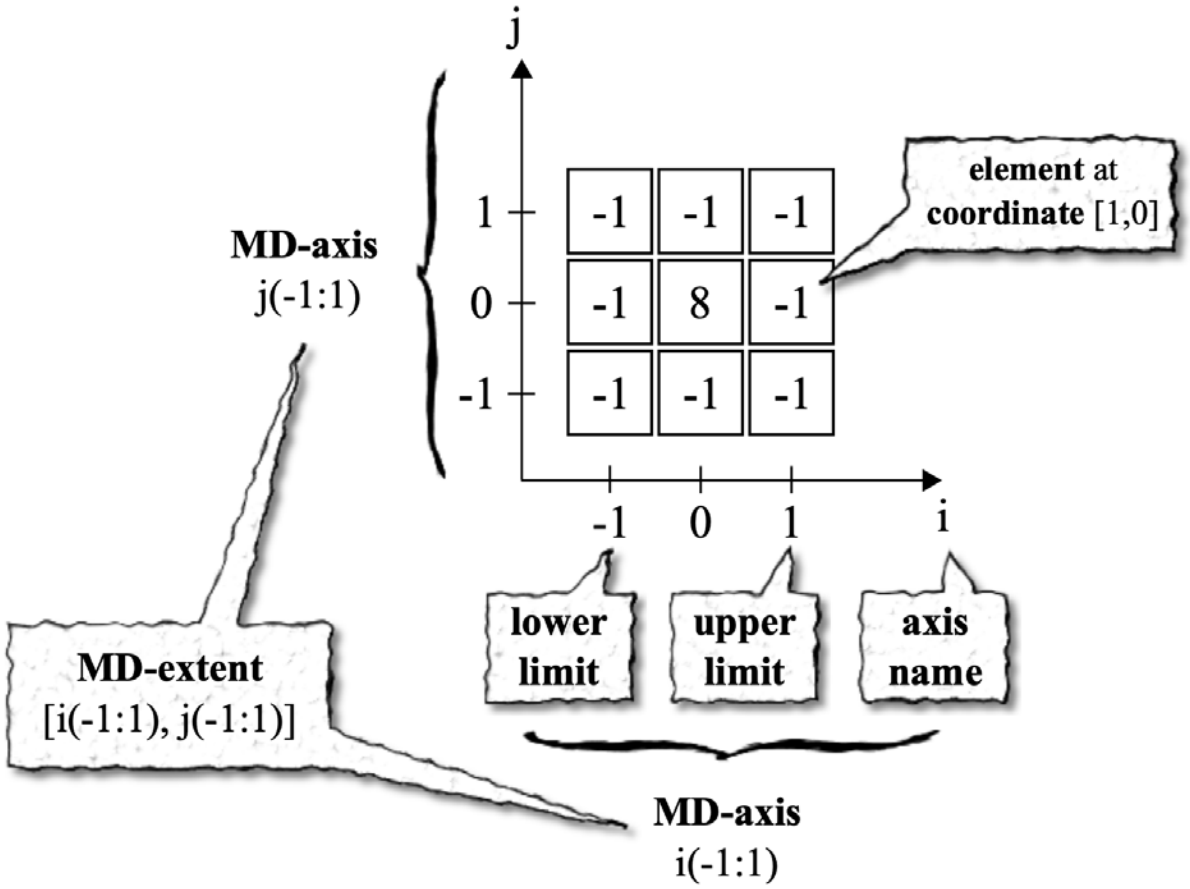


Acknowledgements

- Parts of subsequent presentations are taken from

  Dimitar Mišev, Peter Baumann, SQL Support for Multidimensional Arrays
  Jacobs Universität, Technical Report No. 34, July **2017**

Array Data Model



MD-arrays Constructed by Element Enumeration

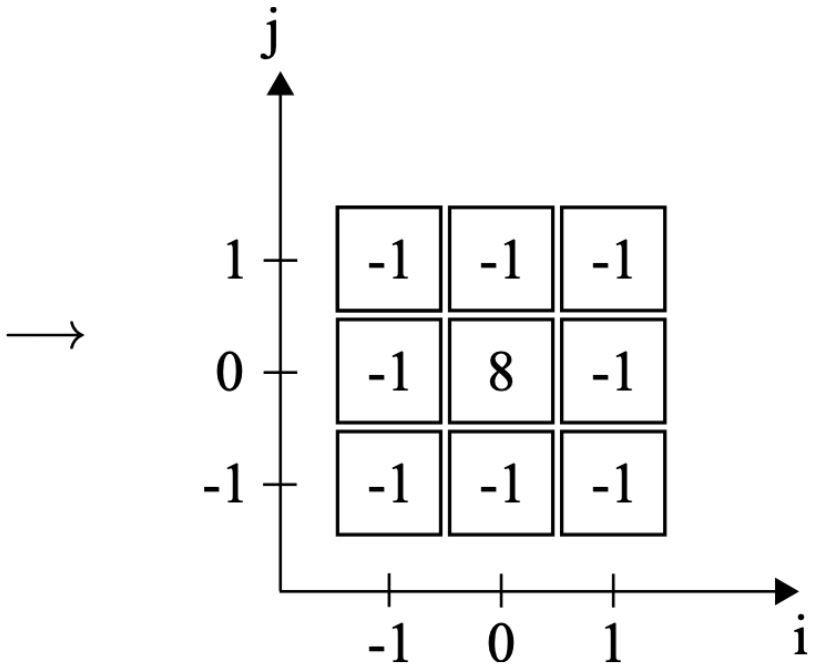
Example	SQL fragment
1-D MD-array of 10 floating-point elements at coordinates ranging from [10] to [19]. The element at coordinate [10] is −0.5, at [11] is −1.5, and so on.	`MDARRAY [temp(10:19)] [-0.5, -1.5, -0.34, 0.1, 1.12, 0.34, 1.5, 0.2, 1.15, 0.033]`
2-D 3x3 convolution kernel, as shown on Figure 4. The element at coordinate [0,0] is 8, which is the 5th element in the `<md-array element list>`, while the elements at all other coordinates are −1.	`MDARRAY [i(-1:1), j(-1:1)] [-1, -1, -1, -1, 8, -1, -1, -1, -1]`
3-D 2x2x2 MD-array of 8 SMALLINT elements, such that the element with value 1 is at coordinate [0,1,2], 2 is at coordinate [0,1,3], 3 at [0,2,2], 4 at [0,2,3], 5 at [1,1,2], and so on.	`MDARRAY [x(0:1), y(1:2), z(2:3)] [1, 2, 3, 4, 5, 6, 7, 8]`

MD-arrays Created with Constructor by Iteration

Example	SQL fragment
2-D constant MD-array such that the value of each element is 0 (zero).	`MDARRAY [x(0:9), y(0:9)]` `ELEMENTS 0`
1-D "gradient" MD-array of 10 elements, in which the value of each element is equal to its coordinate.	`MDARRAY [x(0:9)]` `ELEMENTS x`
2-D "gradient" MD-array of 100 elements, in which the value of each element is equal to the sum of its x and y coordinates.	`MDARRAY [x(0:9), y(0:9)]` `ELEMENTS x + y`
2-D MD-array, which is derived from an existing MD-array A with MD-extent [x(0:9),y(0:9)], so that the value of each element in the newly created MD-array is the square of the corresponding element in A. Note that MD-array element referencing is used in this example, which is explained in more detail later in this Technical Report.	`MDARRAY MDEXTENT(A)` `ELEMENTS POWER(A[x, y], 2)`

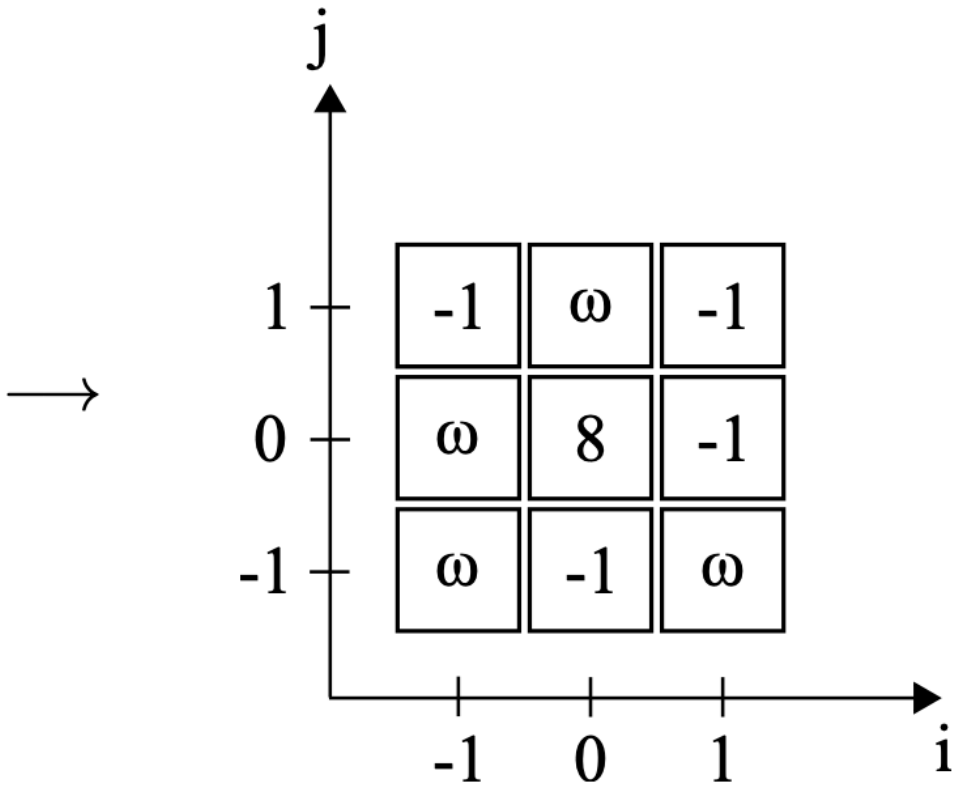
From Tables to Arrays

j	i	element
-1	-1	-1
-1	0	-1
-1	1	-1
0	-1	-1
0	0	8
0	1	-1
1	-1	-1
1	0	-1
1	1	-1



From Tables to Arrays with Nulls (ω)

j	i	element
-1	1	-1
0	-1	-1
0	0	8
1	0	-1
1	1	-1



Array Updates

There are three general patterns that can be observed when updating a target MD-array T with a source value S:

— S and T are MD-arrays of the same MD-dimension;

— S is an MD-array of MD-dimension that is less than the MD-dimension of T;

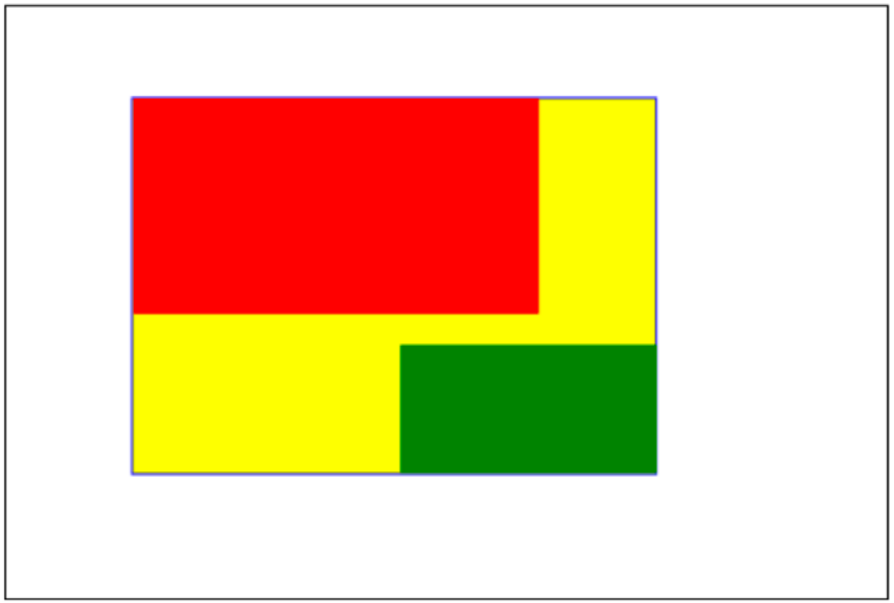
— S is of a compatible type to the element type of T, rather than an MD-array.

```
TABLE Temp(
  T REAL MDARRAY[ t(1:12), x(1:1000), y(1:1000) ]
)
```

```
UPDATE Temp SET T = MDARRAY[t(1:1), x(1:1), y(1:3)] [0.0, 1.0, 2.0]
```

```
UPDATE Temp SET T[t(1:1), x(1:1), y(1:3)] =
  MDARRAY[t(1:1), x(1:1), y(1:3)] [0.0, 1.0, 2.0]
```

Array Updates as an Extension



- Red rectangle: MD-extent of *T* ,
- White rectangle with black border: maximum MD-extent
- Green rectangle: MD-extent of *S*
- Result MD-array of update: rectangle formed of the red, yellow and green parts; elements in the yellow subset are set to null.

From Arrays to Tables

```
SELECT T.* FROM UNNEST(MDARRAY[x(1:2), y(1:2)] [1, 2, 5, 6])
                AS T(x, y, value)
```

x	y	value
1	1	1
1	2	2
2	1	5
2	2	6

ord	x	y	value
1	1	1	1
2	1	1	2
3	2	1	5
4	2	2	6

```
SELECT T.* FROM UNNEST(MDARRAY[x(1:2), y(1:2)] [1, 2, 5, 6])
                WITH ORDINALITY AS T(ord, x, y, value)
```

Examples

```
CREATE TABLE kernels (
  id INT PRIMARY KEY,
  name CHARACTER VARYING(50),
  kernel SMALLINT MDARRAY [i(-100:100), j(-100:100)],
  filter SMALLINT MDARRAY [i(-100:100), j(-100:100)] )

INSERT INTO kernels VALUES
  (1, 'Edge detection',
   MDARRAY [i(-1:1), j(-1:1)] [-1, -1, -1,
                               -1,  8, -1,
                               -1, -1, -1],
   MDARRAY [i(-2:2), j(-2:2)] [2,  4,  5,  4, 2,
                               4,  9, 12,  9, 4,
                               5, 12, 15, 12, 5,
                               4,  9, 12,  9, 4,
                               2,  4,  5,  4, 2])
```

Referencing Elements

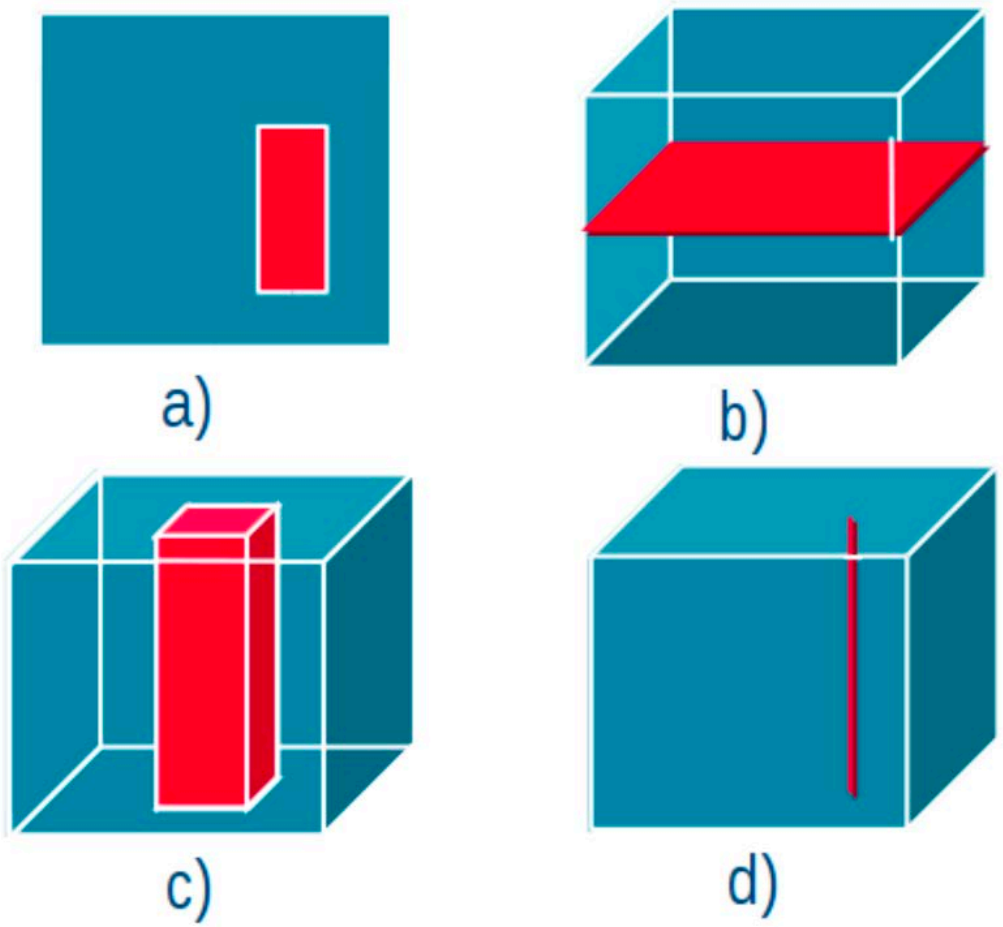
Example	Result

`kernel[0, 0]`
`kernel[i(0), j(0)]`
`kernel[j(0), i(0)]`
	8

`kernel[50, 0]`	null value

`kernel[-1, 1000]`
`kernel[x(0), y(0)]`
`kernel[i(0), 0]`
	error

Projection on Arrays („Subsetting“)



Projection

Example	Result

`kernel[0:1, 0:1]`
`kernel[i(0:1), j(0:1)]`
`kernel[j(0:1), i(0:1)]`
	`MDARRAY [i(0:1), j(0:1)] [8, -1, -1, -1]`

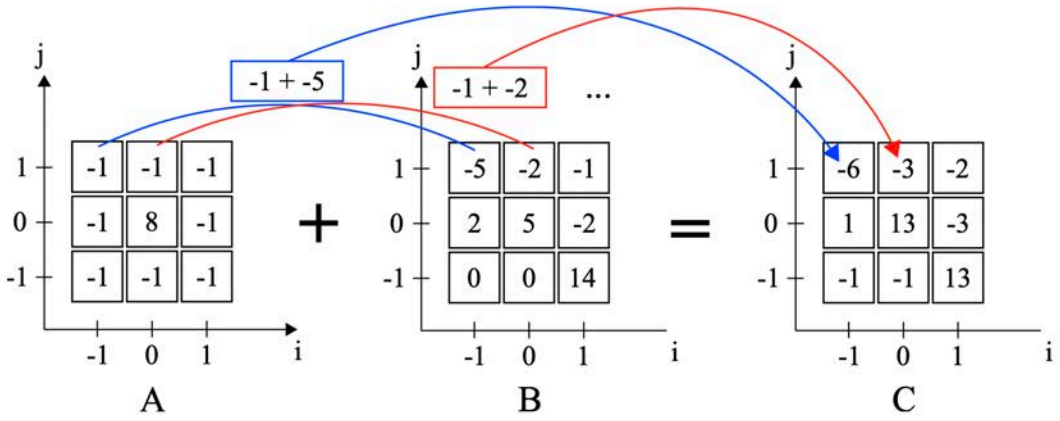
`kernel[0, 0:1]`
`kernel[0, 0:*]`
`kernel[i(0), j(0:1)]`
`kernel[i(0), j(0:*)]`
`kernel[j(0:1), i(0)]`
	`MDARRAY [j(0:1)] [8, -1]`

`kernel[0:0, 0:1]`
`kernel[0:0, 0:*]`
`kernel[i(0:0), j(0:1)]`
`kernel[i(0:0), j(0:*)]`
`kernel[j(0:1), i(0:0)]`
	`MDARRAY [i(0:0), j(0:1)] [8, -1]`

`kernel[0, -1:1]`
`kernel[0, *:*]`
`kernel[i(0)]`
`kernel[i(0), j(*:*)]`
	`MDARRAY [j(-1:1)] [-1, 8, -1]`

Further Array Operations

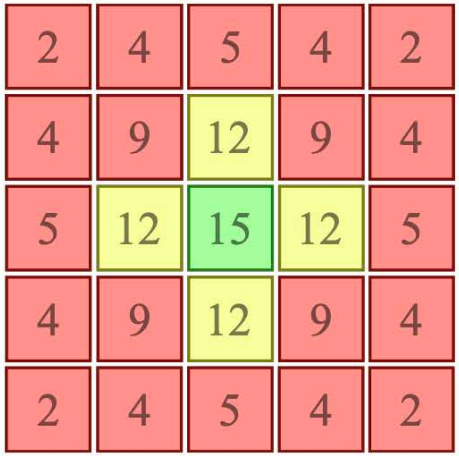
- Reshaping
- Shifting
- Axis renaming
- Scaling
- Concatenation
- Operations
  - Function application
- Cast operations



Array Construction

Example	SQL fragment	Result

Replace negative elements with a 0 (zero), and positive with 1 (one).	`CASE`
	`WHEN kernel <= 0`
	`THEN 0 ELSE 1`
	`END`
		`MDARRAY [i(-1:1), j(-1:1)] [`
		`0, 0, 0,`
		`0, 1, 0,`
		`0, 0, 0]`

Colorize an MD-array with "traffic-light" RGB color scheme (elements smaller than 10 "colored" as red, between 10 and 13 as yellow, and greater than 12 as red).	`CASE`
	`WHEN filter < 10`
	`THEN (255,0,0)`
	`WHEN filter < 13`
	`THEN (255,255,0)`
	`ELSE (0,255,0)`
	`END`
		

Joins on Arrays

- MDJOIN performs a join on two or more MD-arrays of equal MD-extents based on their coordinates
- Let A be defined as MDARRAY [x(0:2)] [1, 2, 3] and B as MDARRAY [x(0:2)] [4.1, 6.12, -0.2]

Example	Result type	Result value
`MDJOIN(A, B, A)`	`ROW(FIELD1 SMALLINT, FIELD2 FLOAT, FIELD3 SMALLINT) MDARRAY [x(0:2)]`	`MDARRAY [x(0:2)] [ ROW(1, 4.1, 1), ROW(2, 6.12, 2), ROW(3, -0.2, 3) ]`
`MDJOIN(A AS red, B AS green, A AS blue)`	`ROW(red SMALLINT, green FLOAT, blue SMALLINT) MDARRAY [x(0:2)]`	`MDARRAY [x(0:2)] [ ROW(1, 4.1, 1), ROW(2, 6.12, 2), ROW(3, -0.2, 3) ]`

Decoding/Encoding

- Arrays from/to JSON structures
- Arrays from/to TIFF files
- …

Example	SQL fragment
1-D "gradient" JSON array of 6 elements, in which the value of each element is equal to its coordinate.	`MDDECODE('{ "data": [1, 2, 3, 4, 5, 6] }', 'application/json' RETURNING INT MDARRAY [x(1:6)])`
2-D MD-array from a 3x3 convolution kernel array encoded as JSON (cf. Figure 4).	`MDDECODE('{ "data": [[-1, -1, -1], [-1, 8, -1], [-1, -1, -1]] }', 'application/json' RETURNING INT MDARRAY [i(-1:1), j(-1:1)])`
3-D MD-array from a 1x3x2 array encoded as JSON.	`MDDECODE('{ "data": [[[1, 2], [3, 4], [5, 6]]] }', 'application/json' RETURNING INT MDARRAY [t(0:0), x(0:2), y(0:1)])`

Scalability for Array Query Answering

- Scalability by specific partitioning techniques to distribute array data over multiple computing nodes
- Transactions across machines automatically managed for updates

Applications

- Image processing (e.g., photogrammetry)
- (Static) time series (e.g., histograms)

Summary SQL:2016 and Beyond

- Data structures in SQL
  - (Multi-)Sets of records (tables of tuples)
  - Trees of nested semi-structured objects (XML and JSON)
  - Multidimensional arrays (unnested)
  - Graphs
- Each structure with respective data definition and query language elements

Dynamic Time Series Data

- Occur in many application scenarios (e.g., sensor networks)
  - Could be seen implemented as an extensible 1D-array
  - Could be implemented in a table [Timestamp, sensor, measurements…]
- Two challenges for data insertion and query answering
  - Scaling up: Swapping from disk is expensive
  - Scaling out: Transactions across machines expensive
- Specific features for time series management required to ensure scalability

Acknowledgements

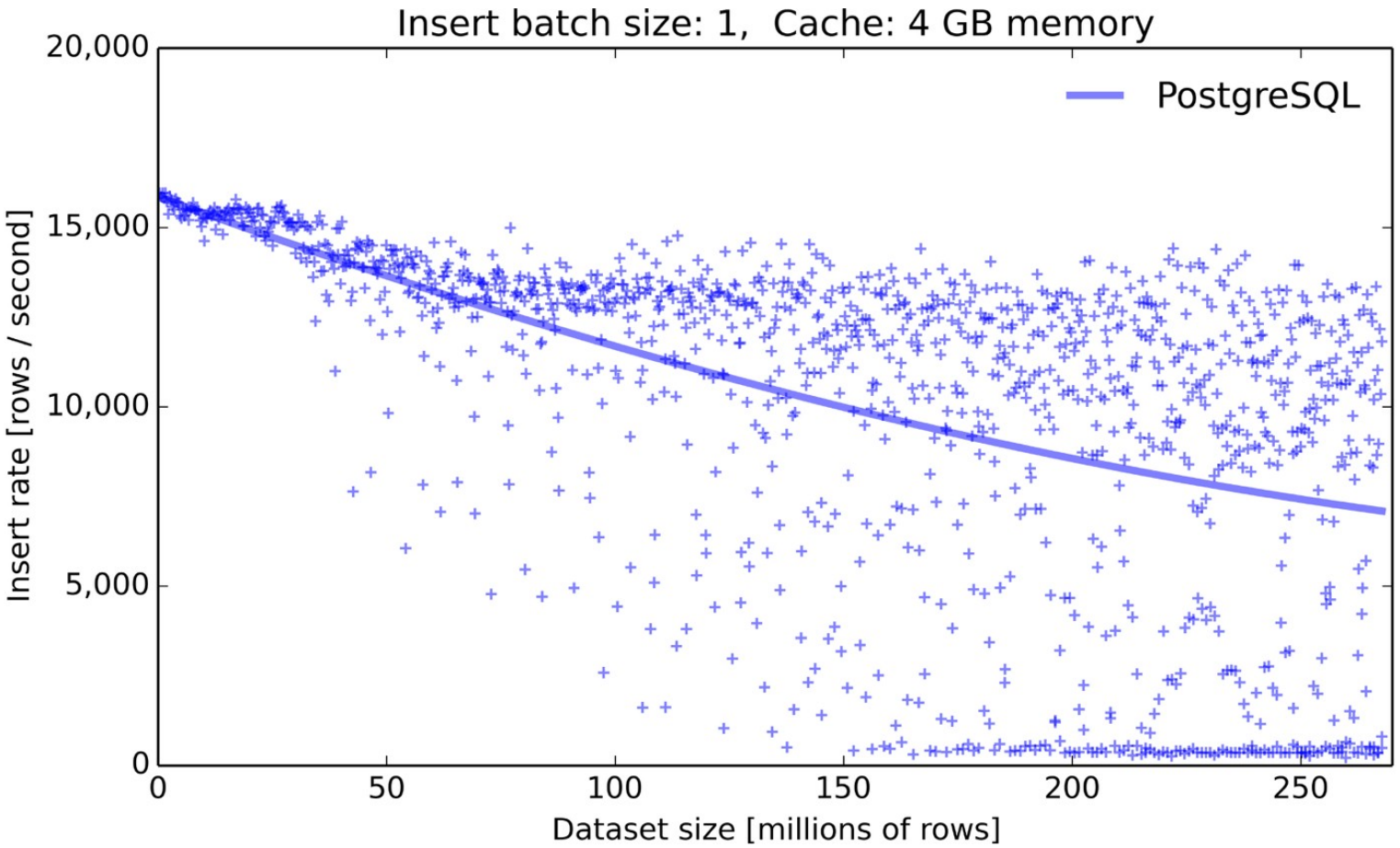
The following slides show diagrams of a presentation provided by timescale.com:

Building a scalable time-series database using Postgres

by Mike Freedman

https://github.com/timescale/timescaledb

Inserting Rows into a Postgres Database



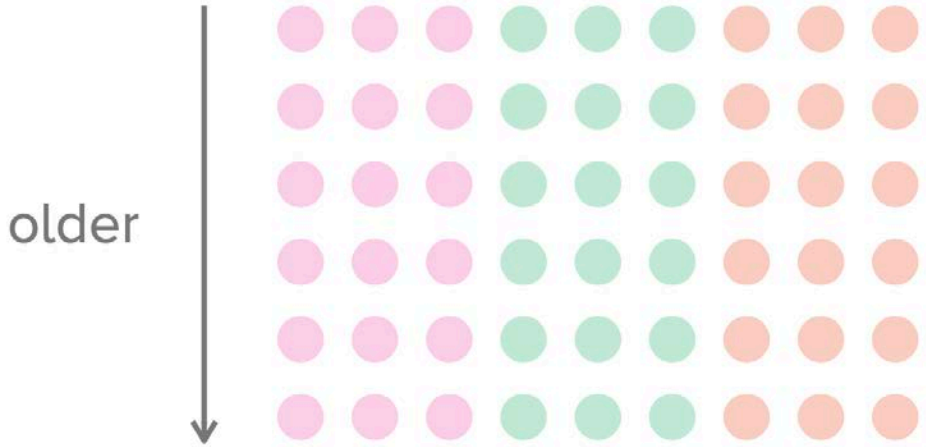
Postgres 9.6.2 on Azure standard DS4 v2 (8 cores), SSD (premium LRS storage)
Each row has 12 columns (1 timestamp, indexed, 1 host ID, 10 metrics)

LRS = Locally redundant storage

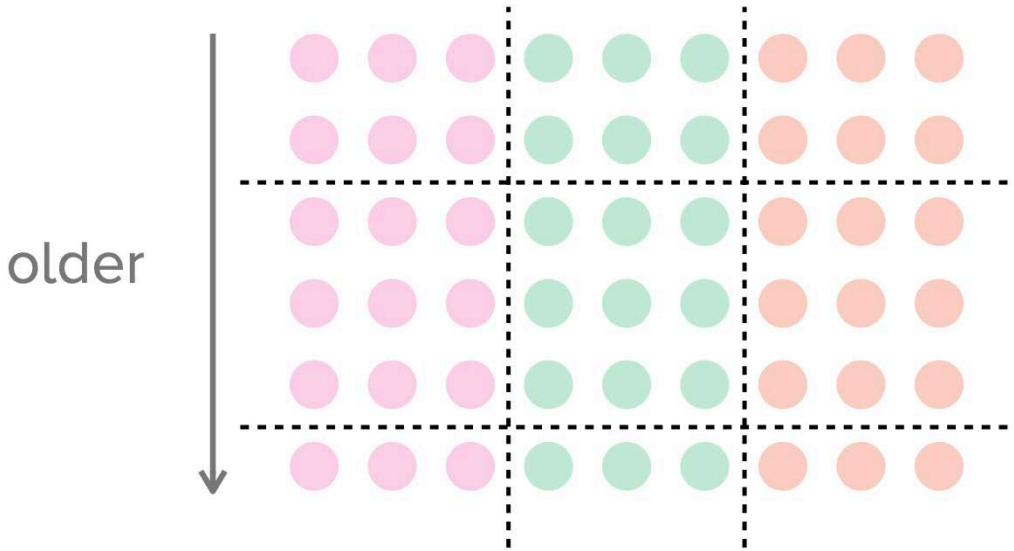
Challenges to scalability

- As tables grow larger
  - Data and indexes no longer fit in memory
  - Reads/writes to random locations in B-tree
  - Separate B-tree for each secondary index
- I/O amplification makes it worse
  - Reads/writes at full-page granularity (8KB), not individual series elements
  - It doesn't help to shrink DB page:
    - HDD still seeks
    - SSD has min Flash page size

Application Scenario



Adaptive time/space partitioning

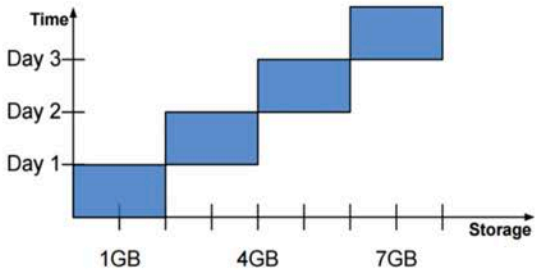


How EXACTLY do we partition by time?

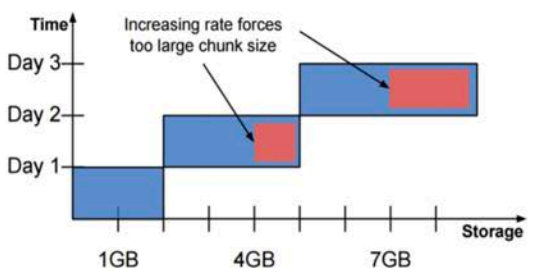
Static, fixed duration?

- Insufficient: Data volumes can change

Fixed-duration intervals: Normal



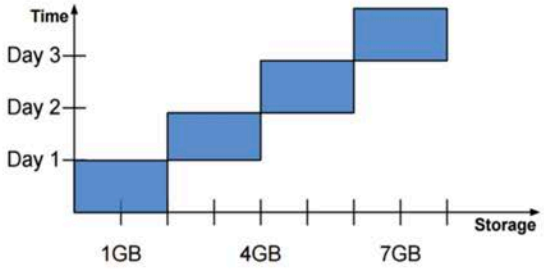
Fixed-duration intervals: With increasing data rates



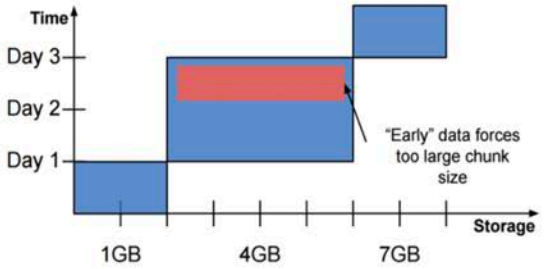
Fixed target size?

- Early data can create too long intervals
- Bulk inserts expensive

Fixed-size chunks: Normal



Fixed-size chunks: With early data

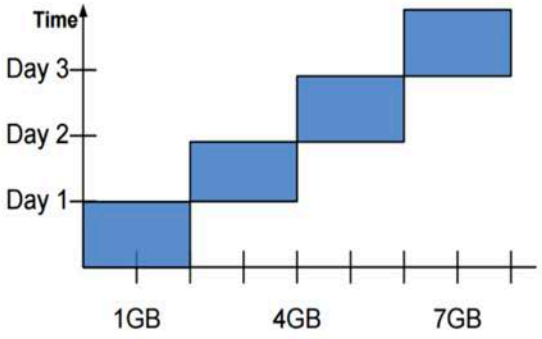


Adaptive time/space partitioning benefits

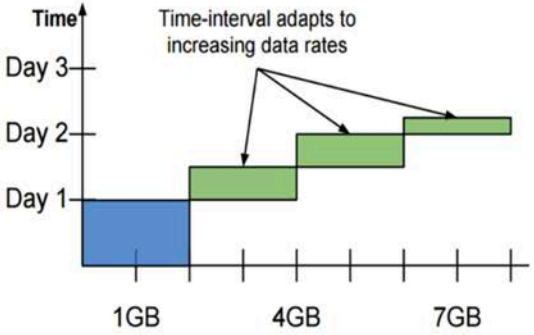
New approach: Adaptive intervals

- Partitions created with fixed time interval, but interval adapts to changes in data volumes

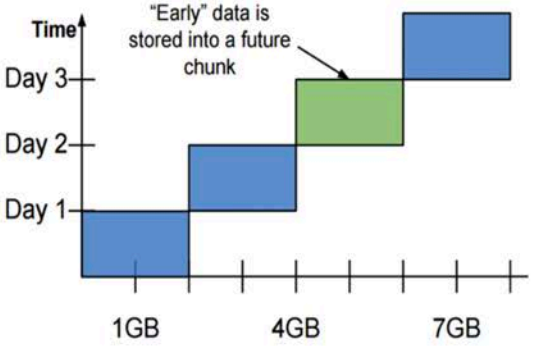
Adaptive chunks: Normal



Adaptive chunks: With increasing data rates



Adaptive chunks: With early data



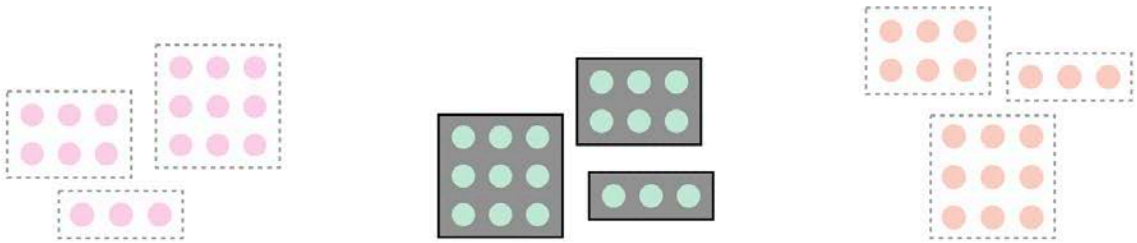
Adaptive time/space partitioning benefits

- **Partitions spread across servers**
- **No centralized txn manager or special front-end**
  - Any node can handle any INSERT or QUERY
  - Inserts are routed/sub-batched to appropriate servers
  - Partition-aware query optimizations

Partition-aware Query Optimization

- Avoid querying chunks via **constraint exclusion analysis**

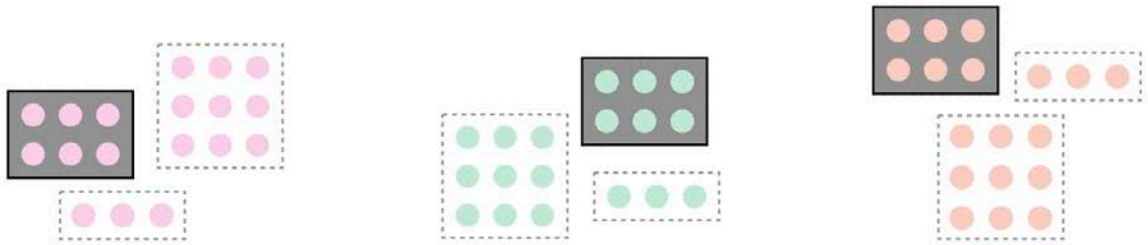
```
SELECT time, temp FROM data
    WHERE  time > now() - interval '7 days'
        AND device_id = '12345'
```



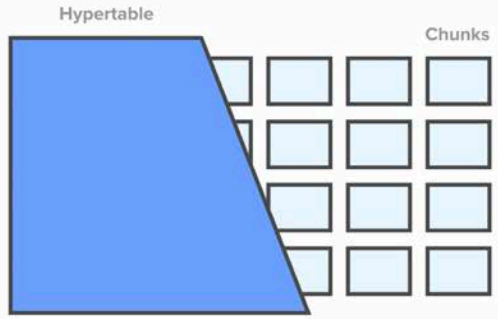
Partition-aware Query Optimization

- Avoid querying chunks via **constraint exclusion analysis**

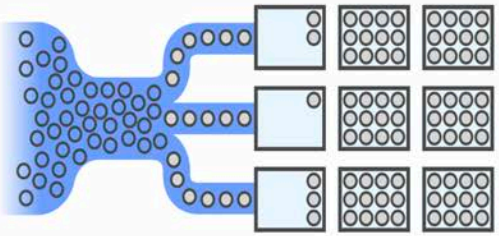
```
SELECT time, device_id, temp FROM data
    WHERE  time > now() - interval '24 hours'
```



Hyper Table Abstraction



- **Illusion of a single table**
- **SELECT against a single table**
  - Distributed query optimizations across partitions

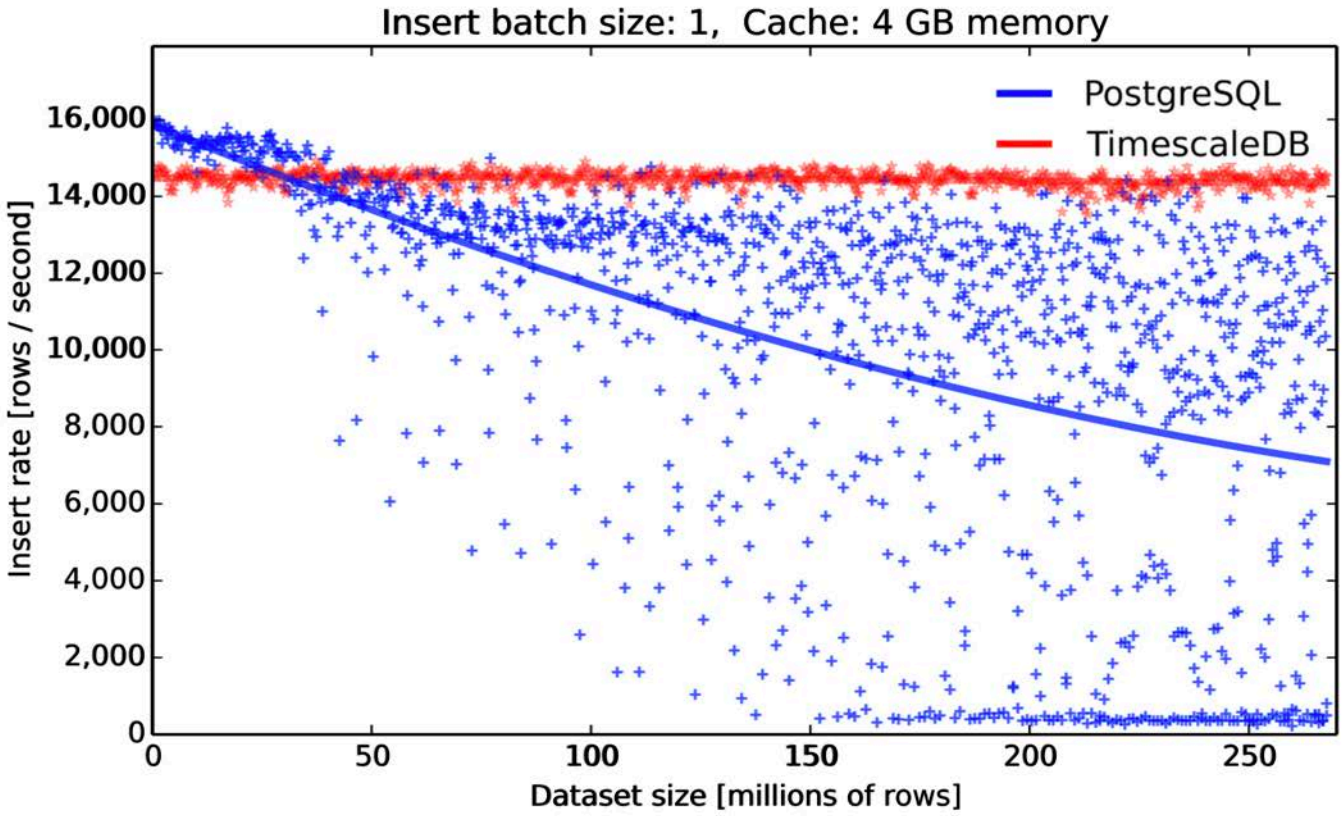


- **INSERT row / batch into single table**
  - Rows / sub-batches inserted into proper partitions
- **Engine automatically closes/creates partitions**
  - Based on both time intervals and table size

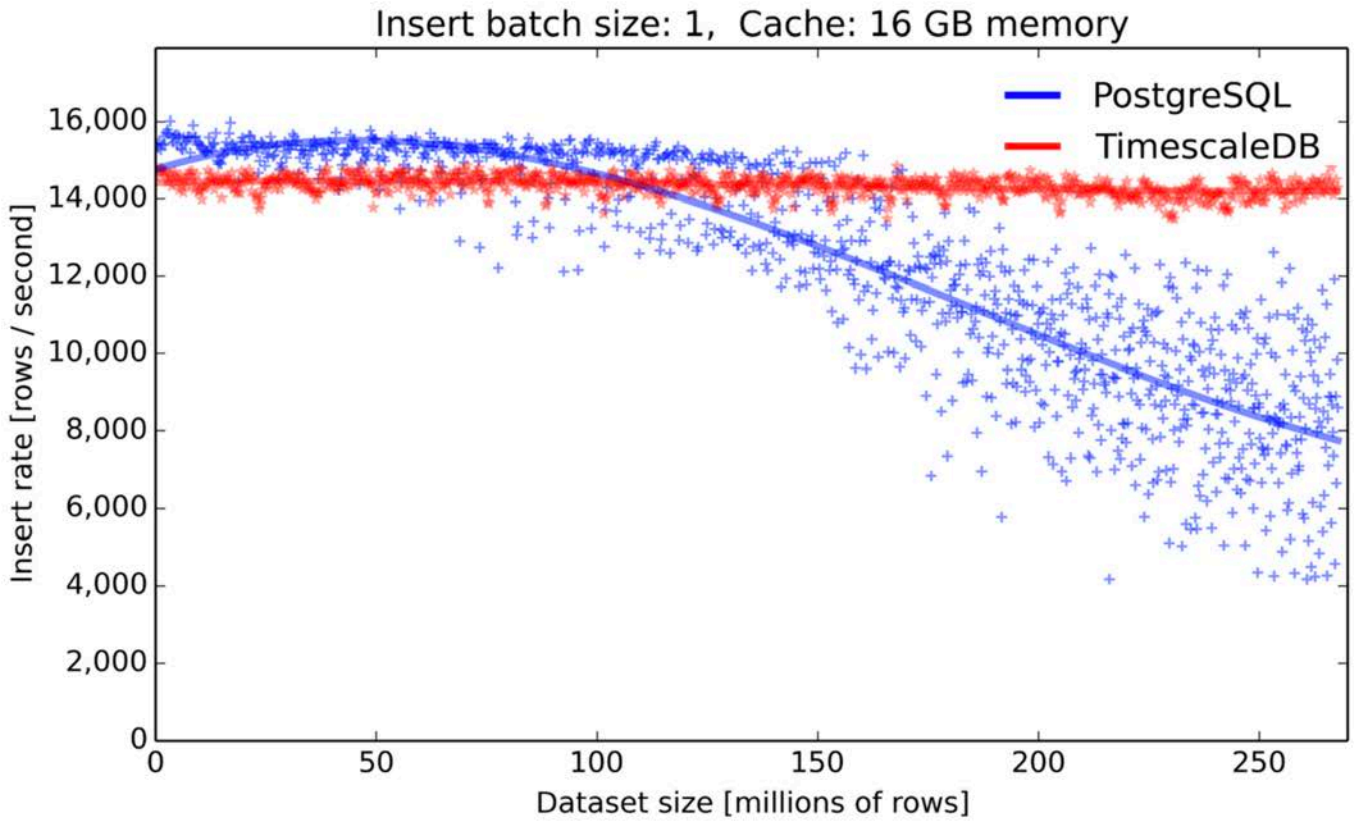
Example: Importing Bulk Data

```
$ psql
psql (9.6.2)
Type "help" for help.

tsdb=#  CREATE TABLE data (
            time TIMESTAMP WITH TIME ZONE NOT NULL,
            device_id TEXT NOT NULL,
            temperature NUMERIC NULL,
            humidity NUMERIC NULL
        );

tsdb=#  SELECT create_hypertable ('data', 'time', 'device_id', 16);

tsdb=#  INSERT INTO data (SELECT * FROM old_data);
```

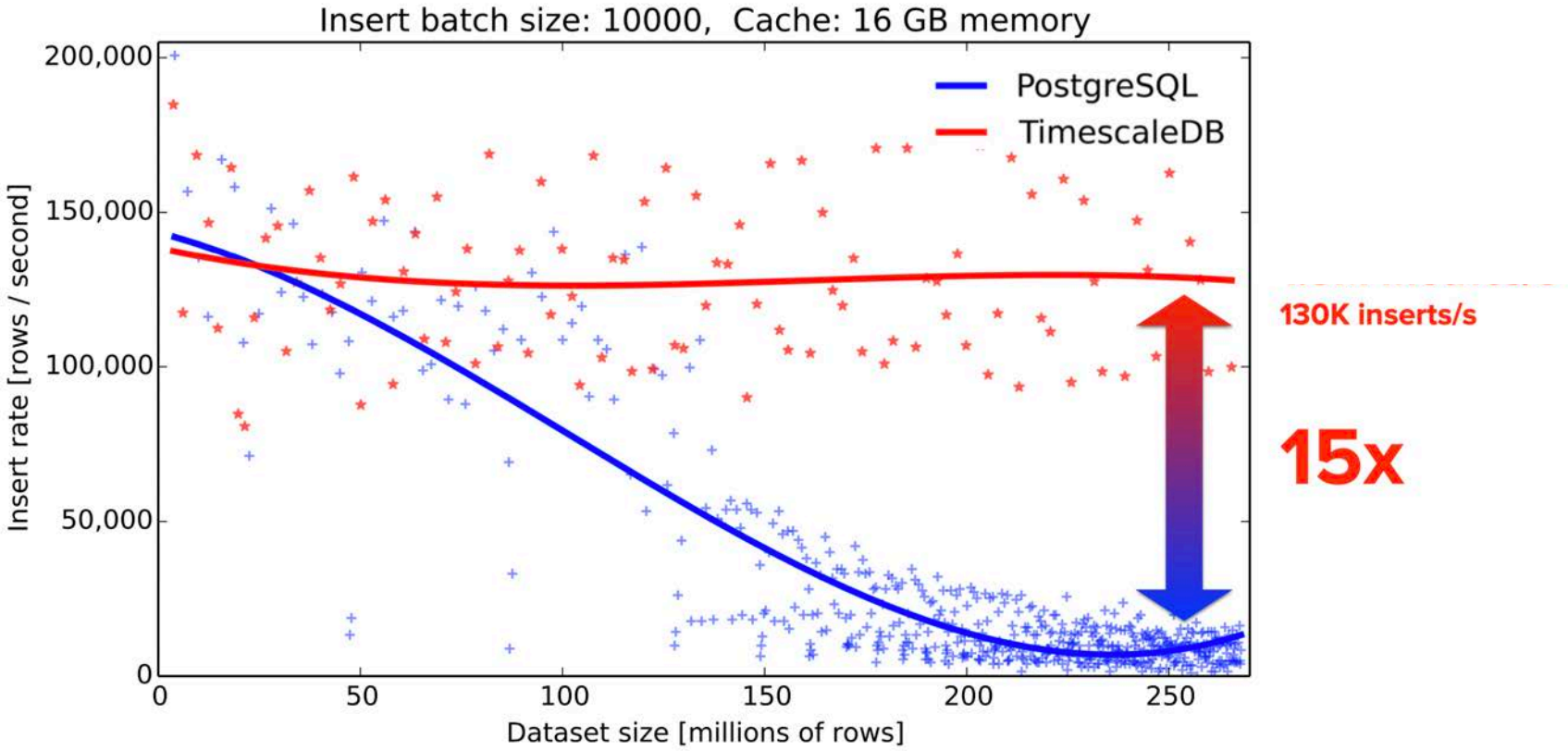
Partitioning column and number of partitions



14.4K inserts/s



14.4K inserts/s


Insert batch size: 10000, Cache: 16 GB memory
PostgreSQL
TimescaleDB
Insert rate [rows / second]
200,000
150,000
100,000
50,000
0
0
50
100
150
200
250
Dataset size [millions of rows]
130K inserts/s
15x

Summary

- Time series support in databases (e.g., sensor data)
  - Example: TimescaleDB.com
- Time/space partitioning to ensure scalability
  - Example: TimescaleDB „hypertables“
- Bulk reading performance improved
- Partitioning-aware query optimization
  - TimescaleDB also much more efficient than Postgres for some queries referring to time data

e.g., query “max per minute for all hosts with limit” is SQL:

```
SELECT date_trunc('minute', time) as minute, max(usage) FROM cpu
  WHERE time < '2017-03-01 12:00:00'
  GROUP BY minute
  ORDER BY minute DESC
  LIMIT 5
```

Add on: Timeseries Visualization (Grafana)