AQuery
A Database System for Order

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Motivation
The need for ordered data

- Queries in Finance, Biology, and Network Management depend on order.
- SQL 99 has extensions – the OLAP amendment – that incorporate order to the language but they are clumsy to use.

3-month moving average: the wrong way

month	sales	3-avg
1	100	100
2	120	110
3	140	120
4	140	133
5	130	136

```
SELECT   t1.month,t1.sales,
         (t1.sales+t2.sales+t3.sales)/3
FROM     Sales t1, Sales t2, Sales t3
WHERE    t1.month - 1 = t2.month AND
         t1.month - 2 = t3.month
```

Problems?

- Join eliminates first two months!
- Do we really need a three-way join?
- Can the optimizer make it linear-time?

3-month moving average: the hard way

	month	sales	3-avg
	1	100	100
	2	120	110
	3	140	120
	4	140	133
	5	130	136

Problems?

- "Write-once" query
- Three way join

```
SELECT   t1.month,t1.sales,
         (t1.sales+
         CASE WHEN t2.sales is null AND
                   t3.sales is null
              THEN 2*t1.sales
              WHEN t2.sales is not null AND
                   t3.sales is null
              THEN t2.sales
                   +(t1.sales+t2.sales)/2
              ELSE t2.sales + t3.sales
         END) / 3
FROM     Sales t1
         LEFT OUTER JOIN Sales t2
           ON t1.month - 1 = t2.month
         LEFT OUTER JOIN Sales t3
           ON t1.month - 2 = t3.month
```

3-month moving average: the OLAP way

month	sales	3-avg
1	100	100
2	120	110
3	140	120
4	140	133
5	130	136

```
SELECT   month,sales,
         avg(sales) OVER (ORDER BY month
                ROWS BETWEEN
                2 PRECEDING AND
                CURRENT ROW)

FROM     Sales
```

Problems?

- OVER construct is confined to the SELECT clause
- Awkward syntax

Network Management Query

- Find duration and average length of packets of src-dst flows. A flow from src to dest ends after a 2-minute silence

Packets	src	dst	len	time
	s1	s2	250	1
	s1	s2	270	20
	s2	s1	330	47
	s1	s2	235	141
	s2	s1	280	150
	s2	s1	305	155

```
WITH
 Prec AS (src,dst,len,time,ptime)
 (SELECT  src,dst,len,time,min(time) OVER w
  FROM    Packets
  WINDOW  w AS
          (PARTITION BY src,dst
           ORDER BY time
           ROWS BETWEEN 1 PRECEDING
            AND 1 PRECEEDING)),
 Flow AS (src,dst,len,time,flag)
 (SELECT  src,dst,len,time,
          CASE
            WHEN time-ptime > 120 THEN 1
            ELSE 0
  FROM    Prec),
 FlowID AS (src,dst,len,time,fID)
 (SELECT  src,dst,len,time,sum(flag) OVER w
  FROM    Flow
  WINDOW  w AS
          (ORDER BY src,dst, time
           ROWS UNBOUNDED PRECEDING))
SELECT src,dst,count(*),avg(len)
FROM   FlowID
GROUP  BY src,dst,fID
```

Order in SQL:1999

- Inter-tuple operations require joins or additional query constructs - or both!
- Ordering can only be obtained in specific clauses (e.g., SELECT)

Bottom line:

- Queries become difficult to read
- Cost of execution is larger than necessary (optimization of nested queries is still an open problem)

Idea

- Replace ordered tables (*arrables*) for tables in the data model (inspiration from KSQL by KX systems)
  - Whatever can be done on a table can be done on an *arrable*. Not vice-versa.
- Define order on a per-query basis
  - All query clauses can count on data ordering
- Maintain SQL flavor (upward compatibility to SQL 92) while allowing expressions based on order with no additional language constructs
- Exploit optimization techniques involving order

That's AQuery!

Moving average over Arrables

month	sales	3-avg
1	100	100
2	120	110
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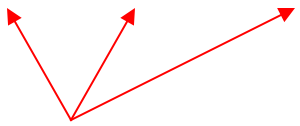

```
SELECT   month,avgs(3,sales)
FROM     Sales
         ASSUMING ORDER month
```

- Arrable: a collection of named arrays, ordered by a column list

Moving average over Arrables

month	sales	3-avg
1	100	100
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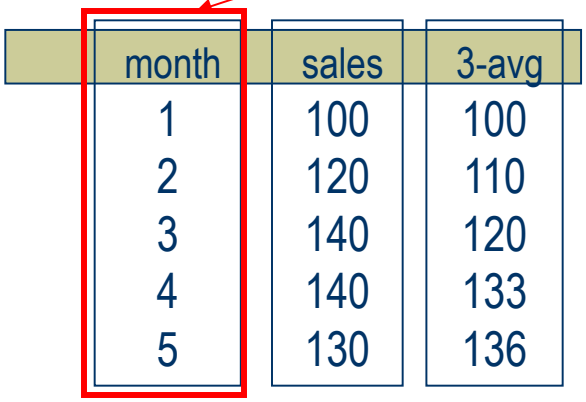
- Arrable: a collection of named arrays, ordered by a column list
- Each query defines data ordering

Moving average over Arrables



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- Arrable: a collection of named arrays, ordered by a column list
- Each query defines data ordering
- Variables (e.g., month) are bound to an array, as opposed to a value

Moving average over Arrables

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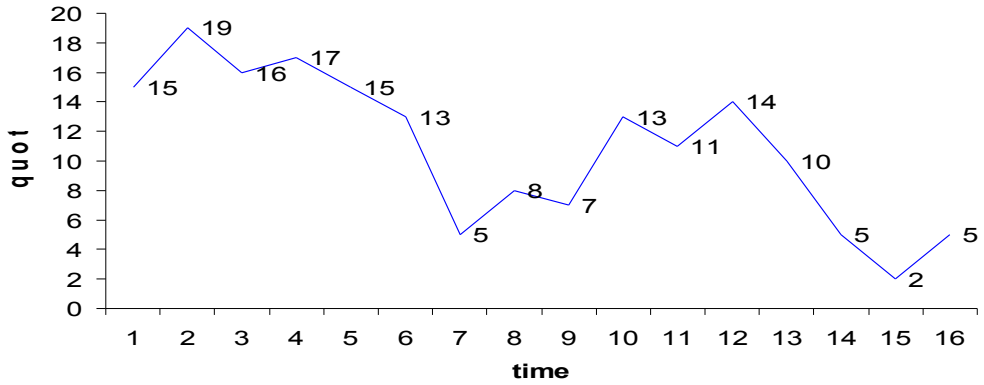
- Arrable: a collection of named arrays, ordered by a column list
- Each query defines data ordering
- Variables (e.g., month) are bound to an array, as opposed to a value
- Expression are mappings from arrays to array

Built-in Functions

	size-preserving	non size-preserving
order-dependent	prev, next avgs, prds, sums, mins, deltas, ratios, reverse, …	drop, first, last
non order-dependent	rank, n-tile	min, max, avg, count

Emotive Query

Find the best profit one could make by buying a stock and selling it later in the same day



price 15 19 16 17 15 13 5 8 7 13 11 14 10 5 2 5

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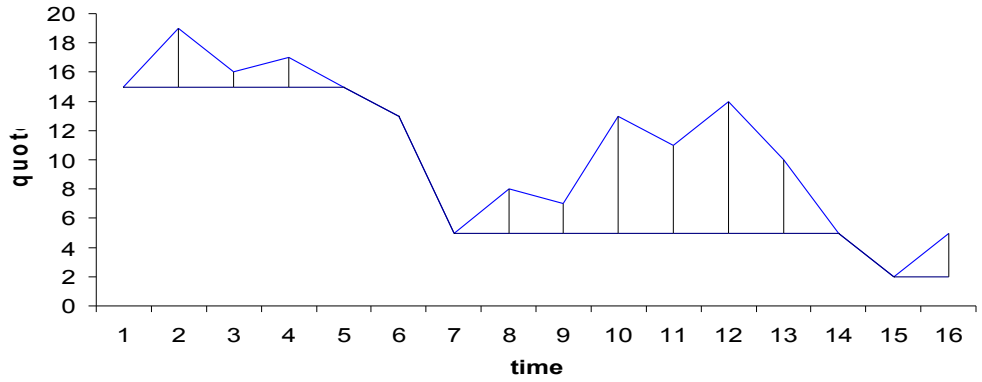


price	15	19	16	17	15	13	5	8	7	13	11	14	10	5	2	5
mins(price)	15	15	15	15	15	13	5	5	5	5	5	5	5	5	2	2
	0	4	1	2	0	0	0	3	2	8	6	9	0	0	0	3

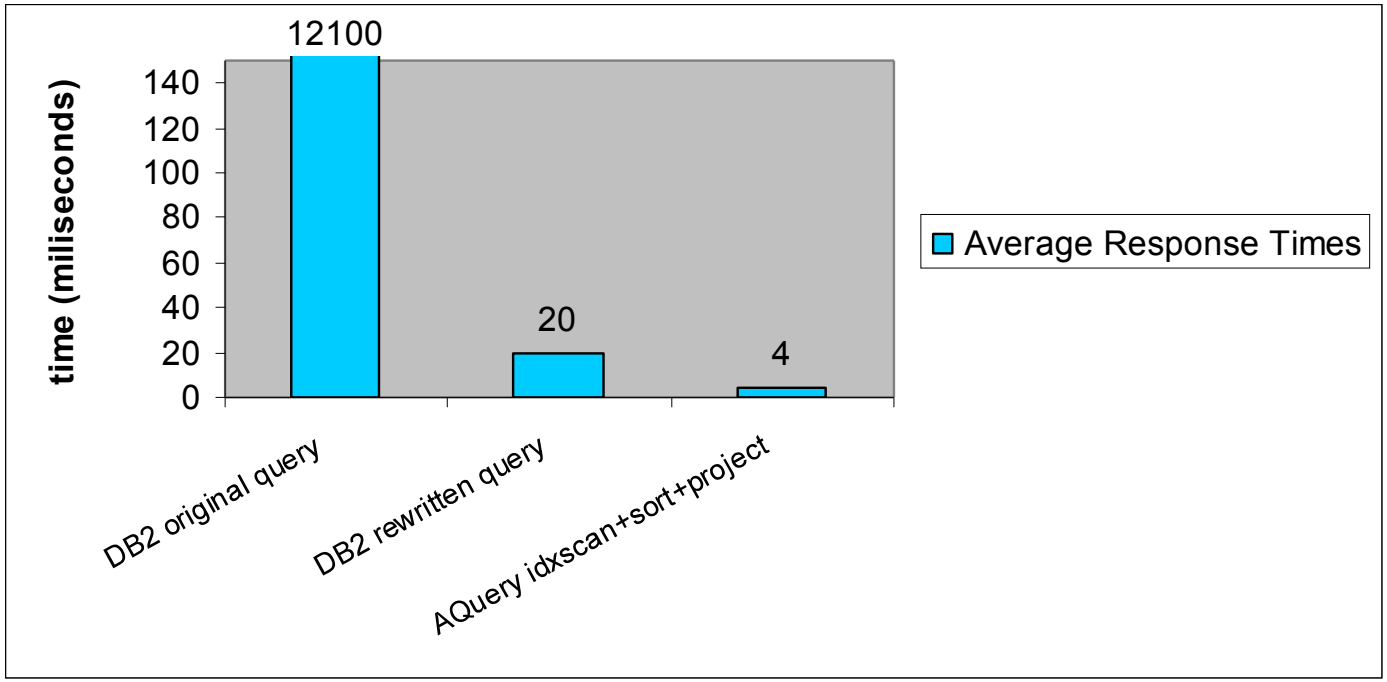
Best-profit Query Comparison

```
[AQuery]
SELECT max(price-mins(price))
FROM   ticks
       ASSUMING timestamp
WHERE  ID="S"
  AND  tradeDate='1/10/03'
```

```
[SQL:1999]
SELECT max(rdif)
FROM   (SELECT ID,tradeDate,
        price - min(price)
          OVER
          (PARTITION BY ID,
                        tradeDate
           ORDER BY timestamp
           ROWS UNBOUNDED
           PRECEDING) AS rdif
        FROM   Ticks ) AS t1
WHERE  ID="S"
  AND  tradeDate='1/10/03'
```

Optimizer doesn't push this selection. To get good performance, the query author has to rewrite it.

Best-profit Query Performance



Complex queries: Network Management Query Revisited

- Create a log of flow information. A flow from src to dest ends after a 2-minutes silence


```
SELECT  src, dst, count(*), avg(len)
FROM    Packets
        ASSUMING ORDER src, dst, time
GROUP   BY src, dst, sums (deltas(time) > 120)
```

Network Management Query in Pictures

Packets	src	dst	len	time
	s1	s2	250	1
	s1	s2	270	20
	s2	s1	330	47
	s1	s2	235	141
	s2	s1	280	150
	s2	s1	305	155

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Network Management Query in Pictures

Packets	src	dst	len	time	c1
	s1	s2	250	1	F
	s1	s2	270	20	F
	s1	s2	235	141	T
	s2	s1	330	47	F
	s2	s1	280	150	F
	s2	s1	305	155	F

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SELECT  src, dst, count(*), avg(len)
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        ASSUMING ORDER src, dst, time
GROUP   BY src, dst, sums (deltas(time) > 120)
```

Network Management Query in Pictures

Packets	src	dst	len	time	c1	c2
	s1	s2	250	1	F	0
	s1	s2	270	20	F	0
	s1	s2	235	141	T	1
	s2	s1	330	47	F	1
	s2	s1	280	150	F	1
	s2	s1	305	155	F	1

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SELECT  src, dst, count(*), avg(len)
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Network Management Query in Pictures

Packets	src	dst	len	time	c1	c2
	s1	s2	250	1	F	0
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	s1	s2	235	141	T	1
	s2	s1	330	47	F	1
	s2	s1	280	150	F	1
	s2	s1	305	155	F	1

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src	dst	len	time
s1	s2	250,270	1,20
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	s2	s1	330	47
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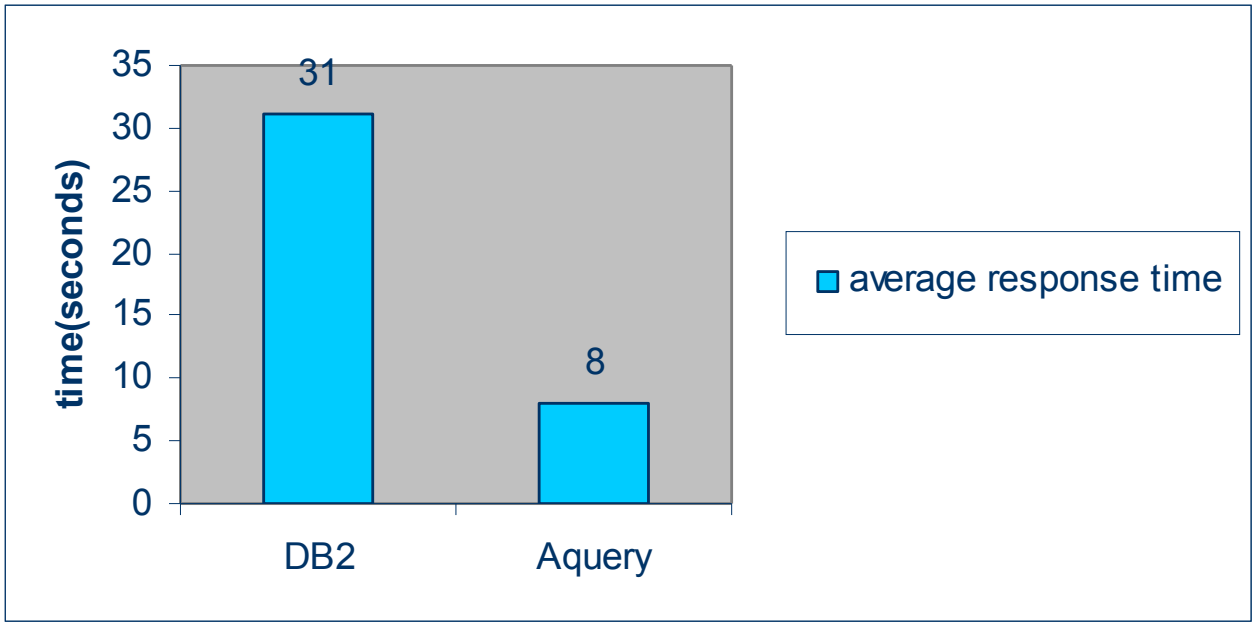
src	dst	len	time
s1	s2	250,270	1,20
s1	s2	235	141
s2	s1	330,280,305	47,150,155

src	dst	avg(len)	count(*)
s1	s2	260	2
s1	s2	235	1
s2	s1	305	3

```
SELECT  src, dst, count(*), avg(len)
FROM    Packets
        ASSUMING ORDER src, dst, time
GROUP   BY src, dst, sums (deltas(time) > 120)
```

Network Management Query Performance



Order-aware Query Languages

- Relations, Sequences, and ordered-relations
  - SQL:1999
  - Sequin (Seshadri et al., 96)
  - SRQL (Ramakrishnan et al., 98)
  - Grouping in SQL (Chatziantoniou and Ross, 96)
- Array query languages
  - AQL (Libkin et al., 96)
  - AML (Marathe and Salem, 97)
  - RaSQL (Widmann and Baumann, 98)
  - KSQL (KX Systems) – our direct ancestor

Order-related Optimization Techniques

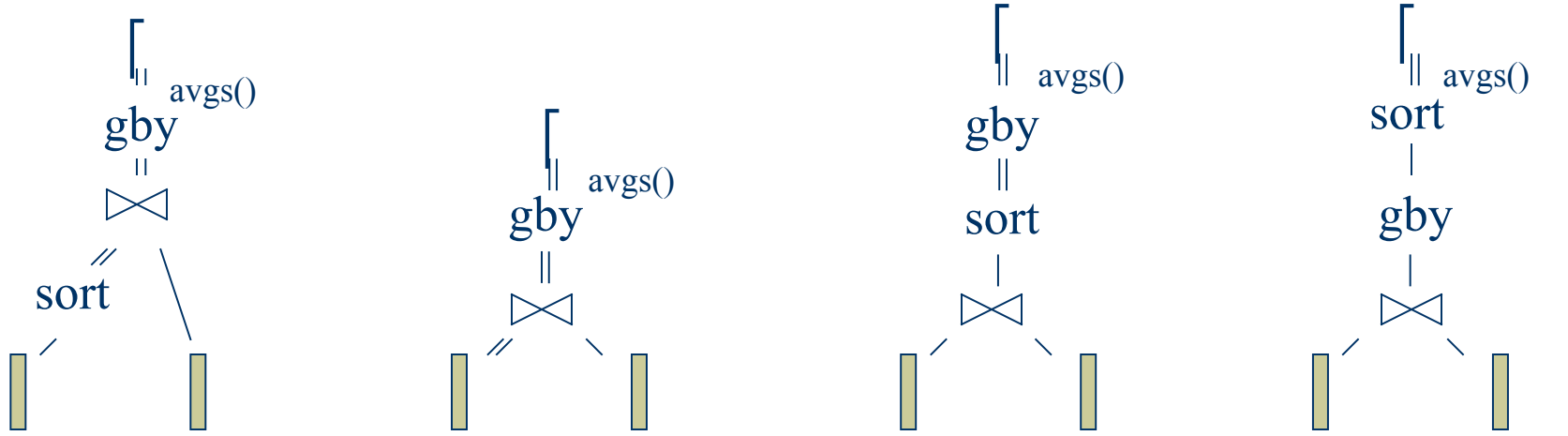
- Starburst's "glue" (Lohman 88) and Exodus/Volcano "Enforcers" (Graefe and McKeena, 93)
- DB2 Order optimization (Simmens et al., 96)
- Top-k query optimization (Carey and Kossman, 97; Bruno,Chaudhuri, and Gravano 02)
- Hash-based order-preserving join (Claussen et al., 01)
- Temporal query optimization addressing order and duplicates (Slivinskas et al., 01)

AQuery Optimization

- Optimization is cost based
- The main strategies are:
  - Define the extent of the order-preserving region of the plan, considering (correctness, obviously, and) the performance of variation of operators
  - Exploit algebraic equivalences
  - Apply efficient implementations of patterns of operators (e.g. “edge-by”)

Interchange sorting + order preserving operators

```
SELECT ts.ID, avgs(10, hq.ClosePrice)
FROM   TradedStocks AS ts NATURAL JOIN
       HistoricQuotes AS hq
       ASSUMING ORDER hq.TradeDate
GROUP  BY Id
```



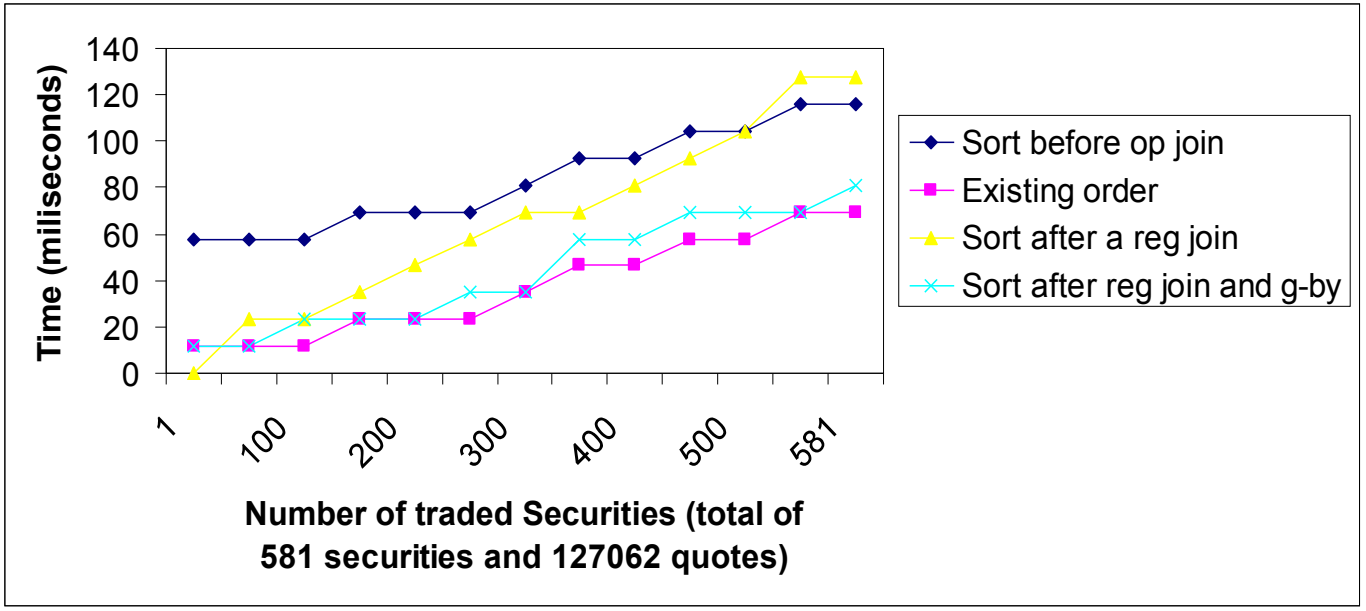
(1) Sort then join preserving order

(2) Preserve existing order

(3) Join then sort before grouping

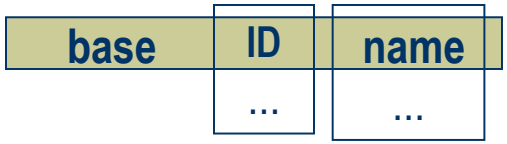
(4) Join then sort after grouping

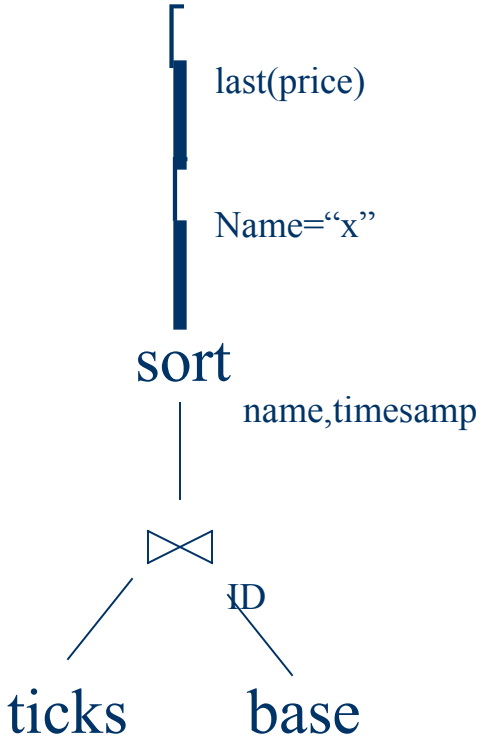
Performance depends on size



Last price for a name query

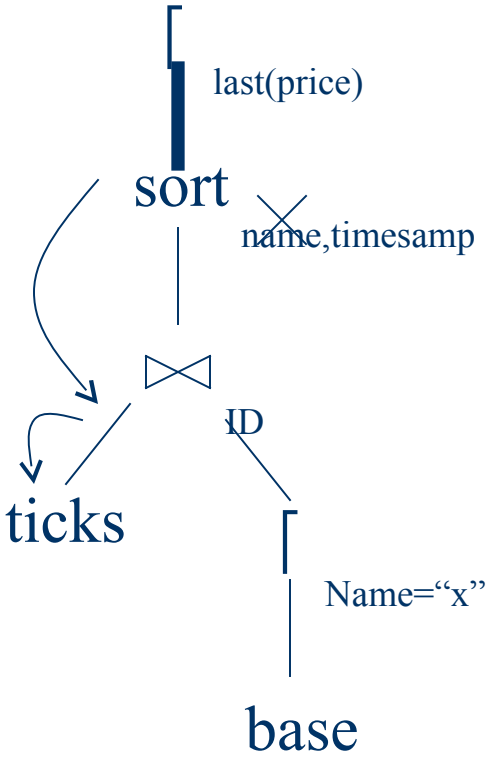
```
SELECT last(price)
FROM   ticks t,base b
       ASSUMING ORDER name,timestamp
WHERE  t.ID=b.ID
       AND name="x"
```





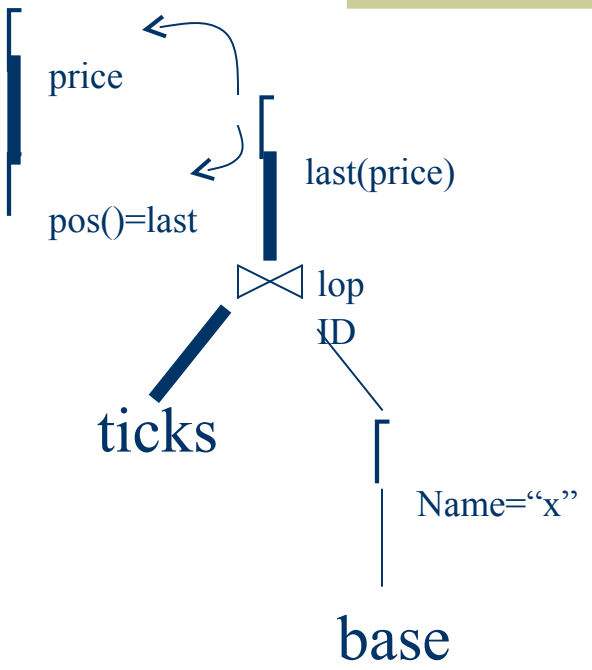
Last price for a name query

- The sort on name can be eliminated because there will be only one name
- Then, push sort
  - $sort_A(r_1 \bowtie r_2) \Gamma_{\ A} sort_A(r_1) \bowtie^{lop} r_2$
  - $sort_A(r) \Gamma_{\ A} r$



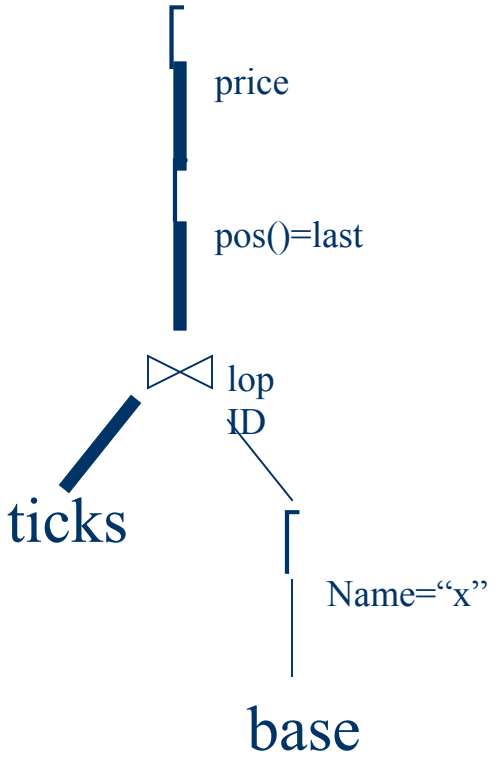
Last price for a name query

- The projection is carrying an implicit selection: last(price) = price[n], where n is the last index of the price array
  - $\Gamma_{f(r.col[i])}(r)\ \Gamma_{order(r)}\ \Gamma_{f(r.col)}(\Gamma_{pos()=i}(r))$



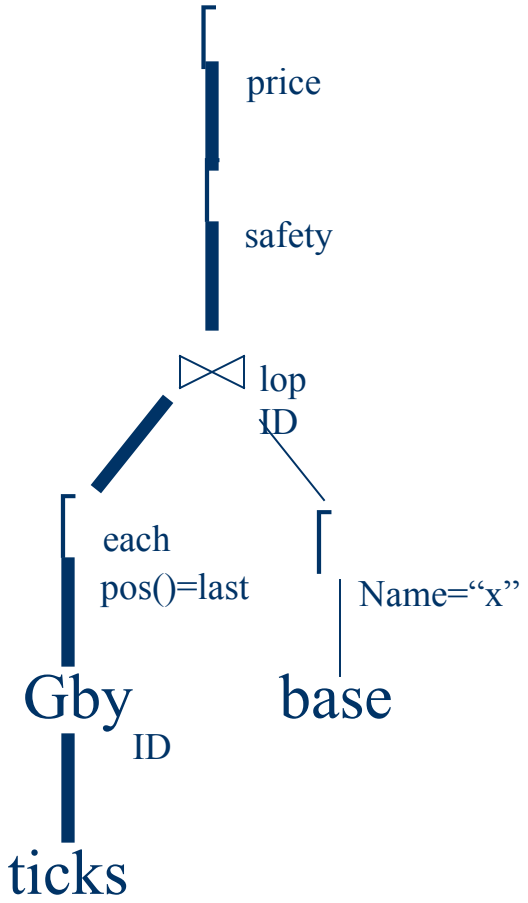
Last price for a name query

- But why join the entire relation if we are only using the last tuple?
- Can we somehow push the last selection down the join?

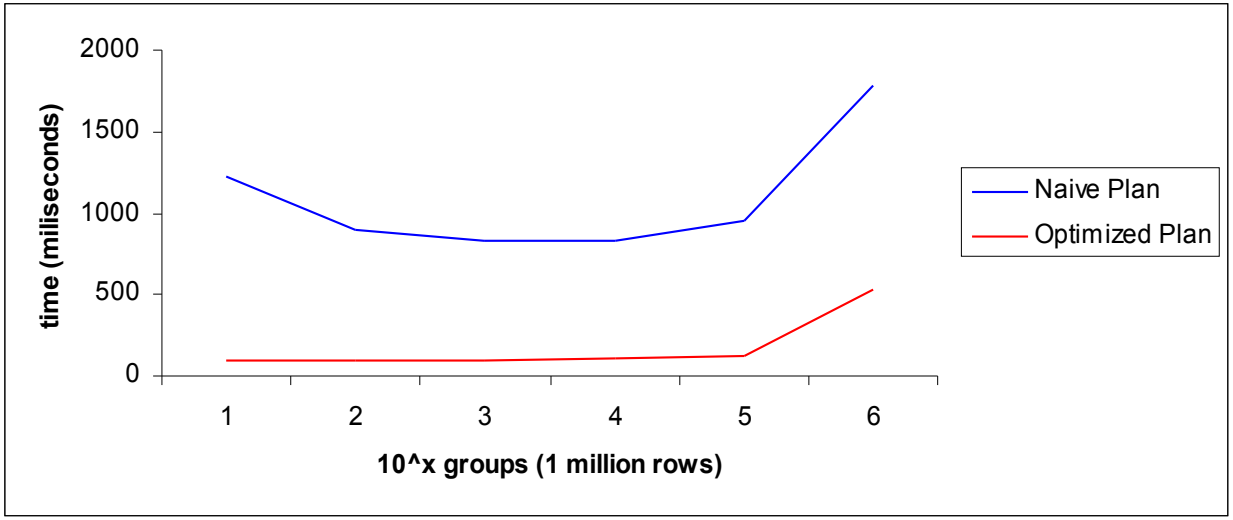


Last price for a name query

- We can take the last position of each ID on ticks to reduce cardinality, but we need to group by ticks.ID first
- But trading a join for a group by is usually a good deal?!
- One more step: make this an “edge by”



Performance



Conclusion

- AQuery declaratively incorporates order in a per-query basis
- Any clause can rely on order; expressions can be order-dependent
- Optimization possibilities are vast; performance improvements of an order of magnitude
- Applications to Finance, Biology, Linguistics, ...

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(for additional references)