Distributed Databases

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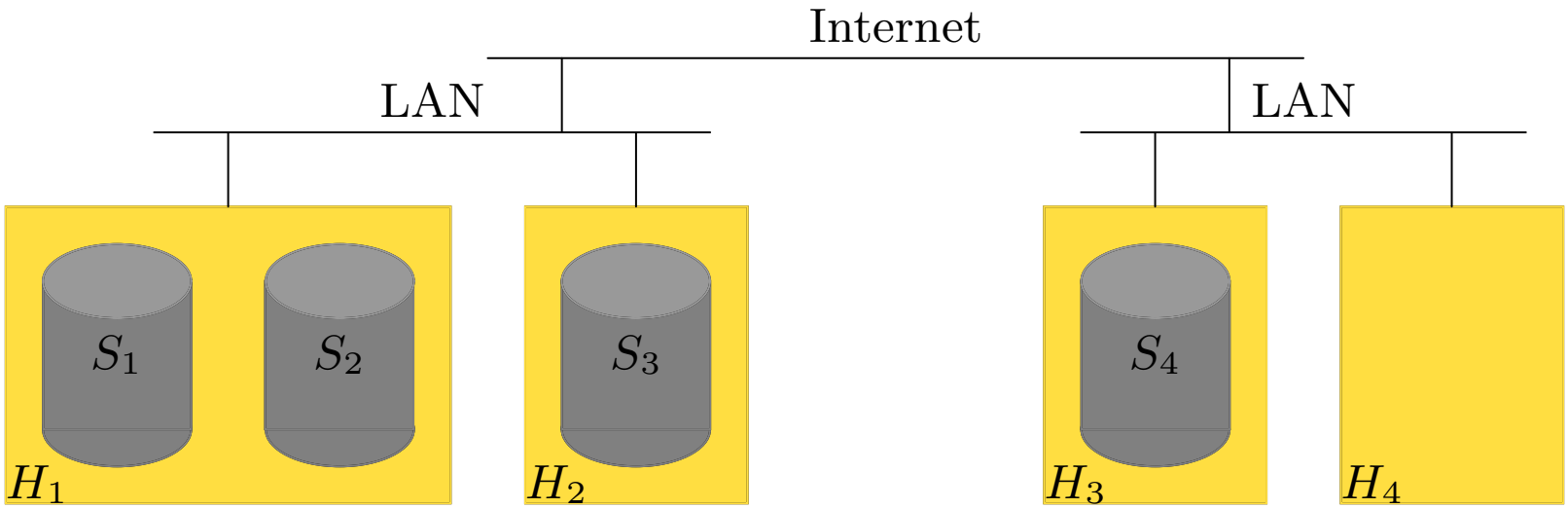
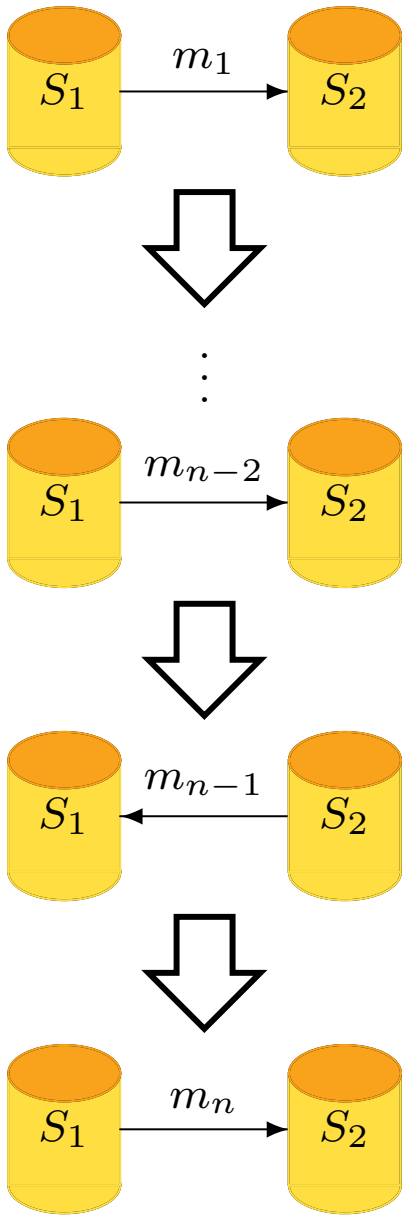


distributed database (DDB)

several databases at different **sites**, connected by

- Server racks
- LAN
- Internet

Coordination Failure with Communication Failure

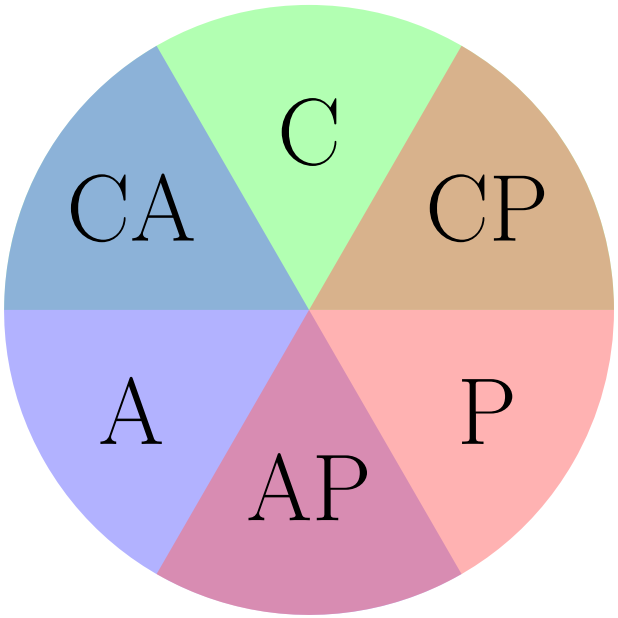


CAP Theorem

CAP Theorem

No distributed system may maintain all three of

- **Consistency**: all nodes see the same version of data
- **Availability**: the system always responds within fixed upper limits of time
- **Partition Tolerance**: the system always gives correct responses even when messages are lost or network failures occur



- CA
  e.g. Centralised Database
- CP
  e.g. Distributed RDBMS
- AP
  e.g. DNS

Distributed Databases: Two Approaches

Heterogeneous DDB

Sites

- vary in database technology
- managed by different DBAs
- designed at different times

Example Architectures

- Data Warehouse
- Mediator

Example Technologies

- ODBC
- JDBC

Homogeneous DDB

Sites

- use same database technology
- managed by one DBA
- designed at same time

Example Architectures

- RDBMS Clusters
- Map Reduce

Example Technologies

- MySQL Cluster
- Hardoop

Distributed Heterogeneous Databases: Physical Differences

Database 1	Database 2

branch

sortcode	bname	cash
55-66-56	'Wimbledon'	94340.45
55-66-34	'Goodge St'	8900.67
55-66-67	'Strand'	34005.00

```
sortcode,bname,cash
"55-66-56","Wimbledon",94340.45
"55-66-34","Goodge St",8900.67
"55-66-67","Strand",34005.00
```

RDBMS	CSV file
Query using SQL	Query by reading file

- Need **common data model** (**CDM**) *e.g.* Relational, ER

Distributed Heterogeneous Databases: Semantic Differences

Database 1	Database 2

branch

sortcode	bname	cash
56	'Wimbledon'	94340.45
34	'Goodge St'	8900.67
67	'Strand'	34005.00

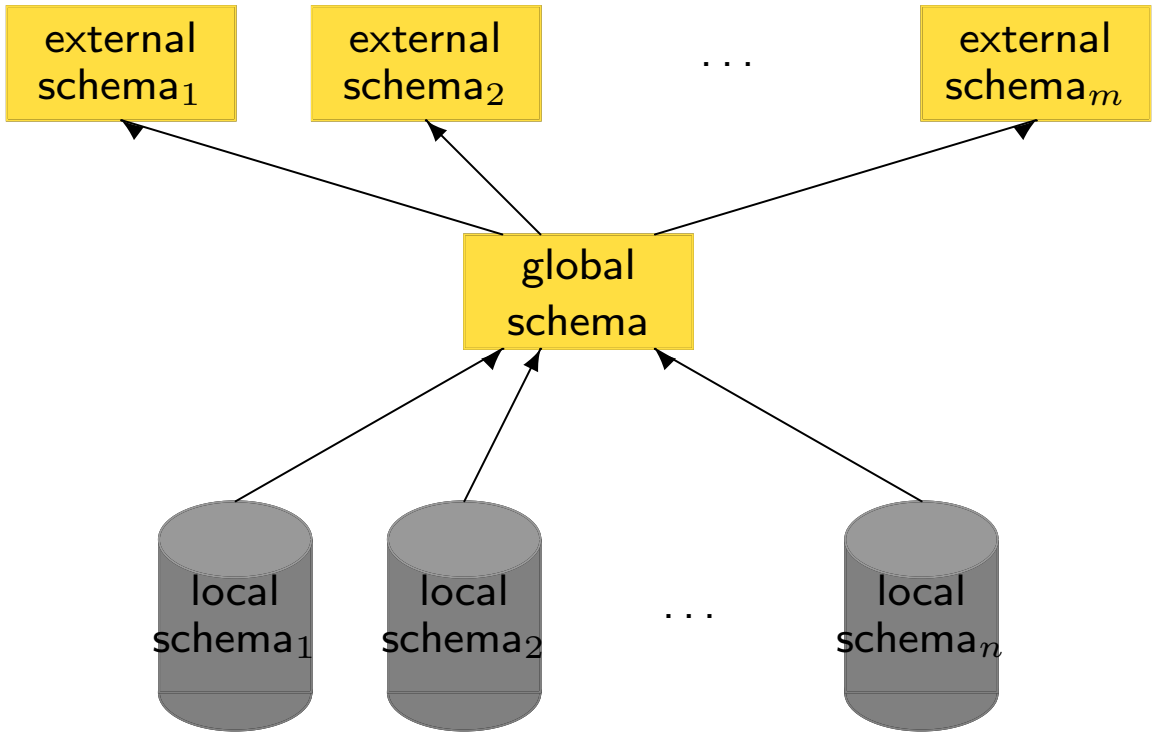
branch

sortcode	branchname	cash
55-66-56	'Wimbledon'	94340.45
55-66-34	'Goodge St'	8900.67
55-66-67	'Strand'	34005.00

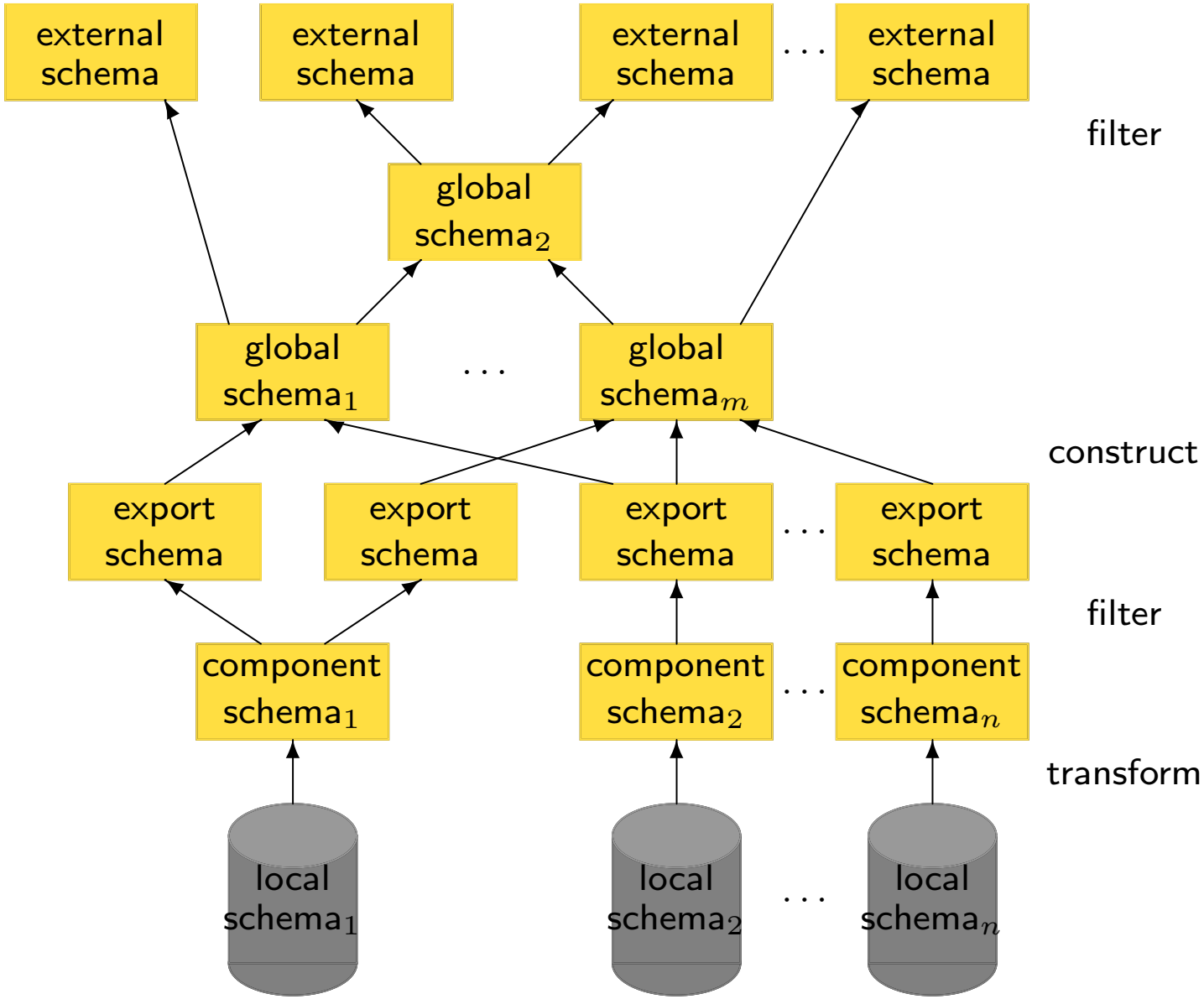
assume 55-66- sortcode	full sortcode
call branches bname	call branches branchname

- Need to perform **schema integration**

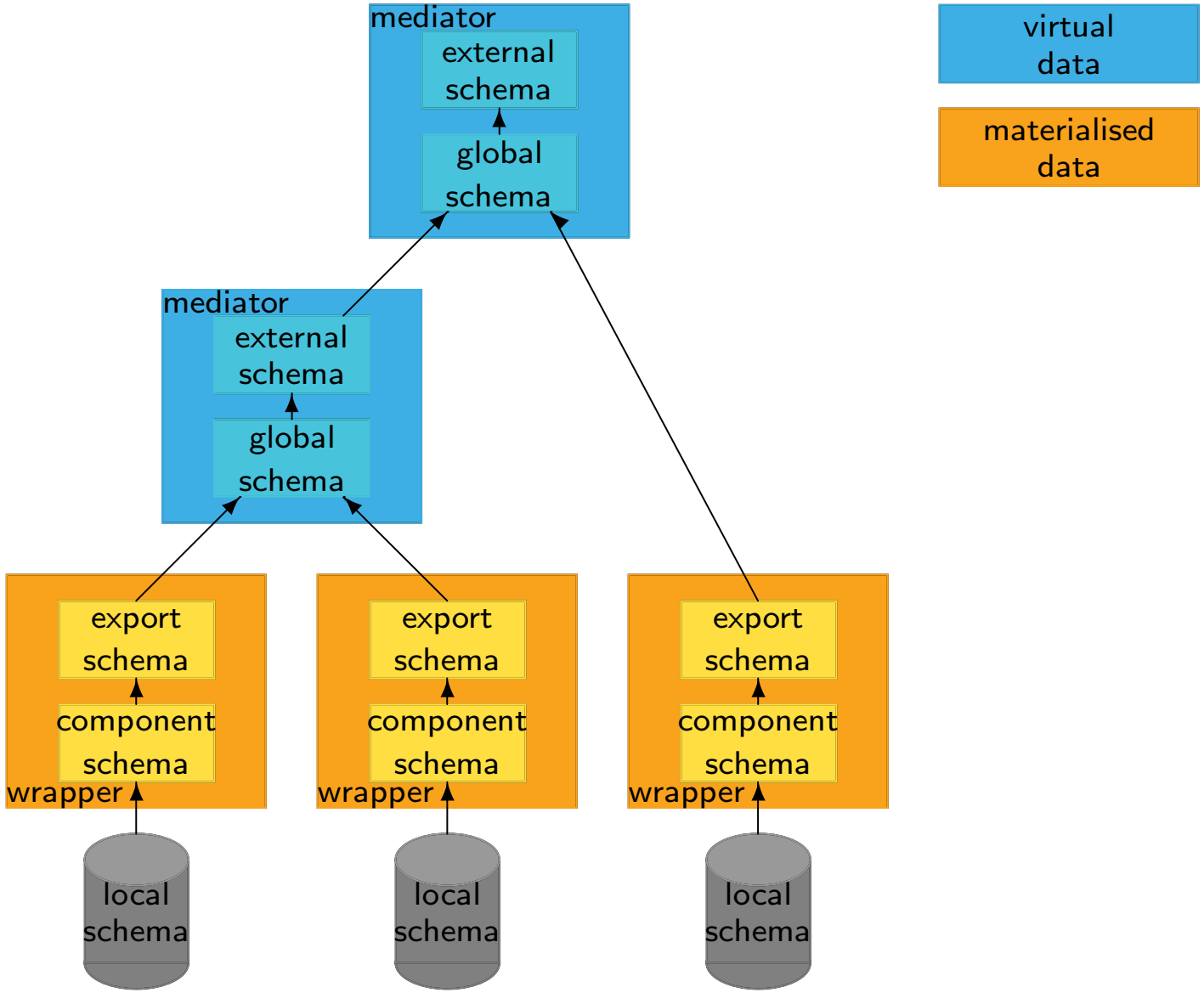
Logical Model for Homogeneous DDB



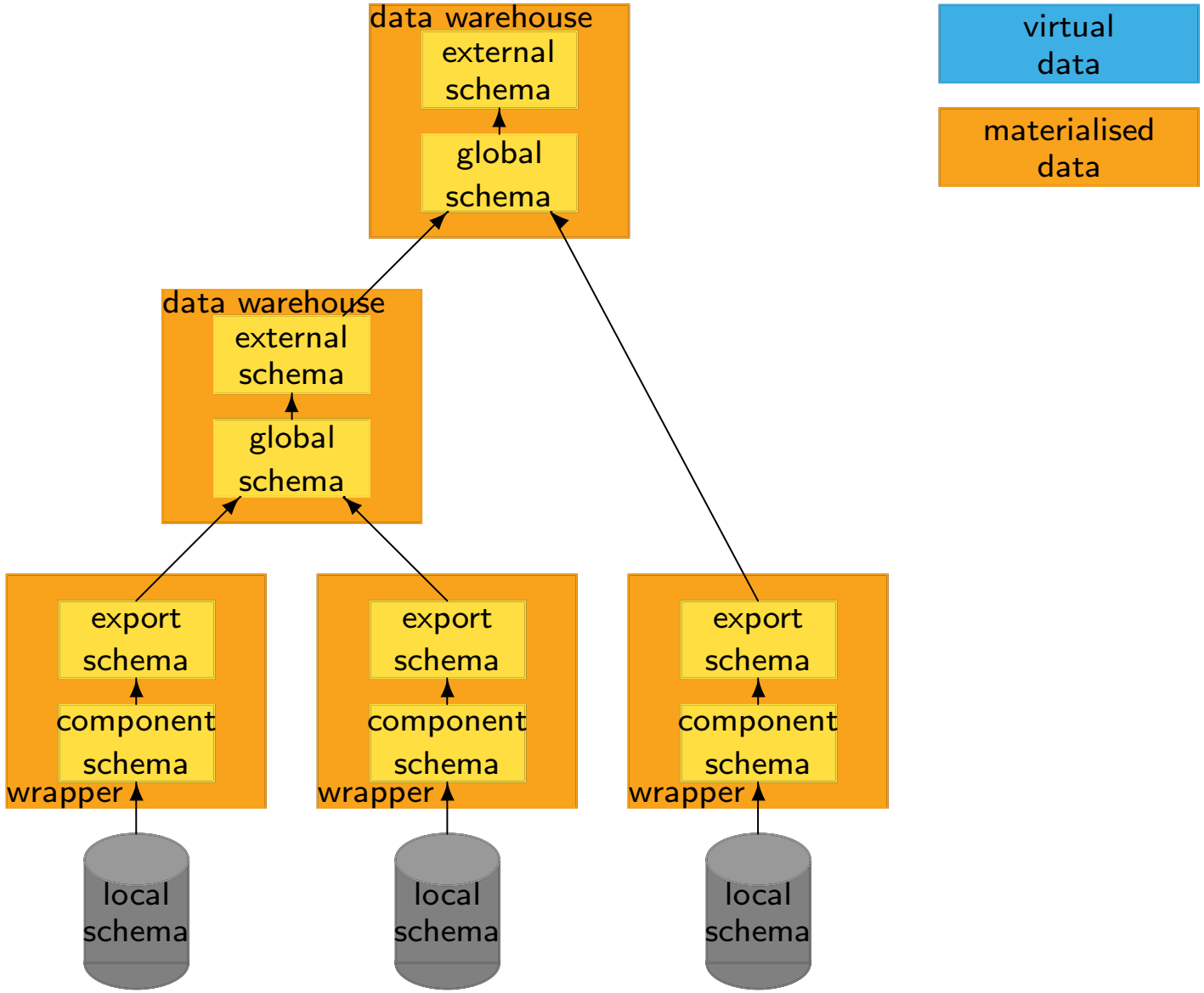
Logical Model for Heterogeneous Databases



Operational Model: Mediator Architecture



Operational Model: Data Warehouses



Topics to Cover in DDB

Operational Aspects

- How might data and hence queries be distributed between local schemas?
- How might a query on the global schema be optimised to run over the local schemas?
- How are ACID properties of transactions maintained in DDB?

Logical Aspects

- How are export schemas integrated to form a global schema?

Data Distribution

branch		
sortcode	bname	cash
56	'Wimbledon'	94340.45
34	'Goodge St'	8900.67
67	'Strand'	34005.00

movement			
mid	no	amount	tdate
1000	100	2300.00	5/1/1999
1001	101	4000.00	5/1/1999
1002	100	-223.45	8/1/1999
1004	107	-100.00	11/1/1999
1005	103	145.50	12/1/1999
1006	100	10.23	15/1/1999
1007	107	345.56	15/1/1999
1008	101	1230.00	15/1/1999
1009	119	5600.00	18/1/1999

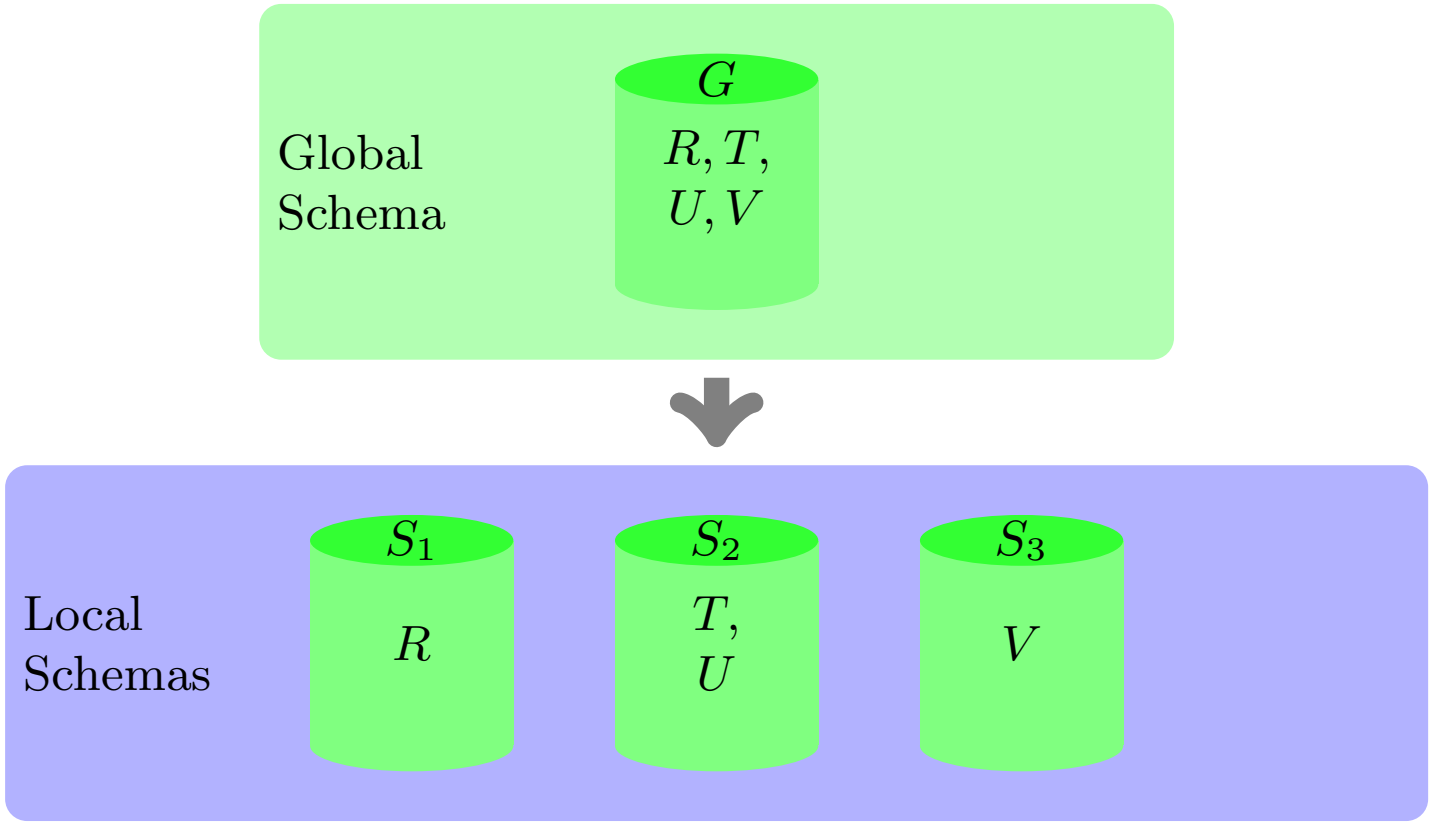
account				
no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

key branch(sortcode)
key branch(bname)
key movement(mid)
key account(no)

movement(no) $\stackrel{fk}{\Rightarrow}$ account(no)

account(sortcode) $\stackrel{fk}{\Rightarrow}$ branch(sortcode)

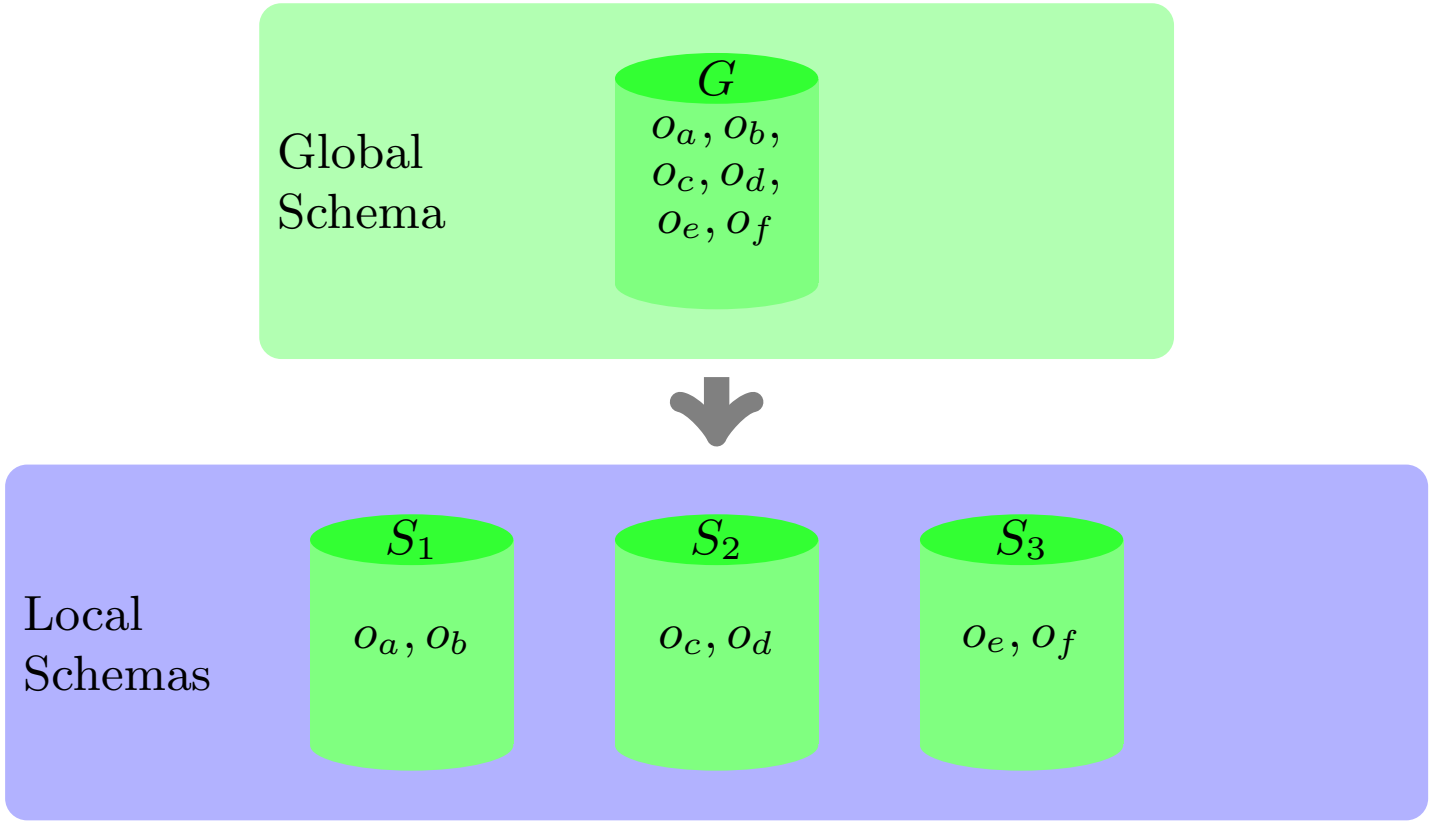
Data Distribution: Remote Tables



remote tables

- split tables $R, T, \ldots$ between sites $S_1, S_2, \ldots$
- reads r and writes w must be correspondingly distributed
  e.g. $r[R], w[R], r[T], r[U] \rightarrow r[R], w[R]$ on S_1 and $r[T], r[U]$ on S_2

Data Distribution: Fragmentation



fragmentation

- split data objects $o_a, o_b, \ldots$ of relation R between sites
- queries and updates must be correspondingly distributed
  $r[o_a], r[o_b], r[o_c] \rightarrow r[o_a], r[o_b]$ on S_1 and $r[o_c]$ on S_2

RDB: Horizontal Fragmentation

Global Schema

account

no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

Local Schemas

$account_1$

no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
125	'current'	'Bailey, J.'	NULL	56

$account_2$

no	type	cname	rate?	sortcode
101	'deposit'	'McBrien, P.'	5.25	67
119	'deposit'	'Poulovassilis, A.'	5.50	56

- $account_1 = \sigma_{type=current} account$
- $account_2 = \sigma_{type \neq current} account$

Quiz 1: Speed and Reliability of Horizontal Fragmentation

account				
no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

```
SELECT  no
FROM    account
WHERE   cname LIKE 'McBrien%'
```

If account is horizontally fragmented on no, compared with a single site version, is the DDB

A

Faster
Less Reliable

B

Faster
More Reliable

C

Slower
Less Reliable

D

Slower
More Reliable

Quiz 2: Horizontal fragmentation attributes

account				
no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

Which is the worst attribute to fragment on?

A
no

B
type

C
cname

D
rate

RDB: Derived Horizontal Fragmentation

movement

mid	no	amount	tdate
1000	100	2300.00	5/1/1999
1002	100	-223.45	8/1/1999
1005	103	145.50	12/1/1999
1006	100	10.23	15/1/1999
1004	107	-100.00	11/1/1999
1007	107	345.56	15/1/1999

S_1

movement

mid	no	amount	tdate
1001	101	4000.00	5/1/1999
1008	101	1230.00	15/1/1999
1009	119	5600.00	18/1/1999

S_2

- $\text{movement}_i = \text{movement} \ltimes \text{account}_i$

Derived Relational Algebra: Semi Join $\ltimes$

Semi Join

$$R \ltimes T = R \bowtie \pi_{Attr(R) \cap Attr(T)} T$$

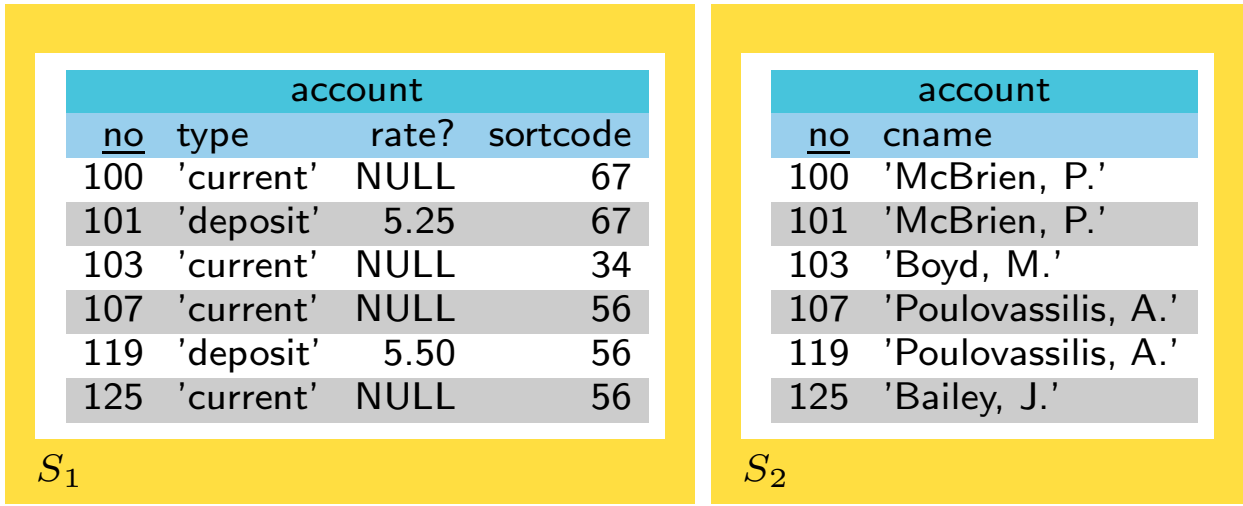
Semi Join

$$\text{account} \ltimes \text{movement} = \text{account} \bowtie \pi_{\text{no}} \text{movement}$$

account $\ltimes$ movement

no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56

RDB: Vertical Fragmentation



account

no	type	rate?	sortcode
100	'current'	NULL	67
101	'deposit'	5.25	67
103	'current'	NULL	34
107	'current'	NULL	56
119	'deposit'	5.50	56
125	'current'	NULL	56

S_1

account

no	cname
100	'McBrien, P.'
101	'McBrien, P.'
103	'Boyd, M.'
107	'Poulovassilis, A.'
119	'Poulovassilis, A.'
125	'Bailey, J.'

S_2

- $\text{account}_1 = \pi_{\text{no,type,rate,sortcode}}\,\text{account}$
- $\text{account}_2 = \pi_{\text{no,cname}}\,\text{account}$

Quiz 3: Vertical Fragmention

branch		
sortcode	bname	cash
56	'Wimbledon'	94340.45
34	'Goodge St'	8900.67
67	'Strand'	34005.00

key(bname)
key(sortcode)

Which of the following is a correct vertical fragmentation of branch?

A

$\pi_{\text{bname,cash}}$ branch
$\pi_{\text{sortcode,cash}}$ branch

B

$\pi_{\text{bname,sortcode}}$ branch
π_{cash} branch

C

$\pi_{\text{bname,cash}}$ branch
π_{sortcode} branch

D

$\pi_{\text{bname,cash}}$ branch
$\pi_{\text{sortcode,bname}}$ branch

RA Definitions

Horizonal Fragmentation

$$R = R_1 \cup \ldots \cup R_n$$

- 'plain' horizontal fragmentation splits rows using σ
  $R_1 = \sigma_{P_1} R, \quad \ldots, \quad R_n = \sigma_{P_n} R$
- derived horizontal fragmentation splits rows using $\ltimes$
  $R_1 = R \ltimes S_1, \quad \ldots, \quad R_n = R \ltimes S_n$
  $R \ltimes S = R \bowtie \pi_{R \cap S}(S)$

Vertical Fragmentation

$$R = R_1 \bowtie \ldots \bowtie R_n$$

- vertical fragmentation splits rows using π
  $R_1 = \pi_{attrs_1} R_1, \quad \ldots, \quad R_n = \pi_{attrs_n} R$
- A **loss-less join** decomposition

Worksheet: Fragmentation

account

no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34

S_1

account

no	type	cname	rate?	sortcode
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

S_2

Worksheet: Fragmentation

account

no	type	sortcode
100	'current'	67
101	'deposit'	67
103	'current'	34
107	'current'	56
119	'deposit'	56
125	'current'	56

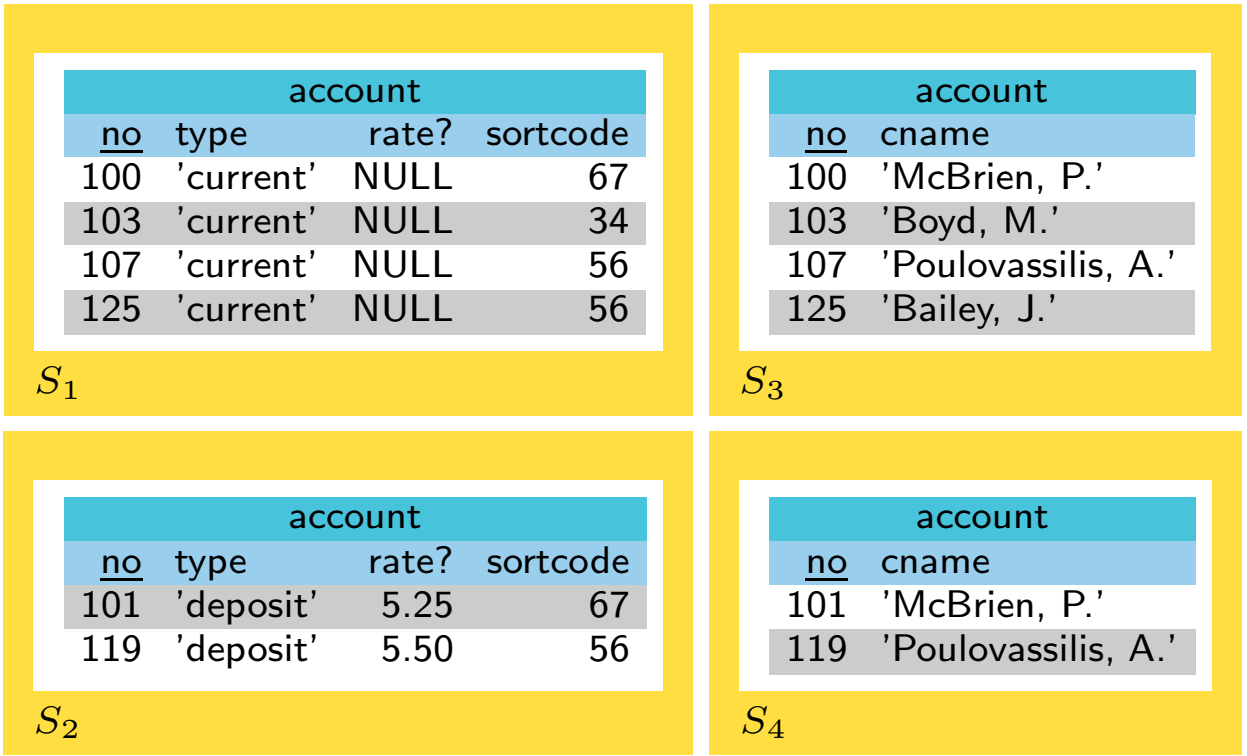
S_1

account

sortcode	cname
67	'McBrien, P.'
67	'McBrien, P.'
34	'Boyd, M.'
56	'Poulovassilis, A.'
56	'Poulovassilis, A.'
56	'Bailey, J.'

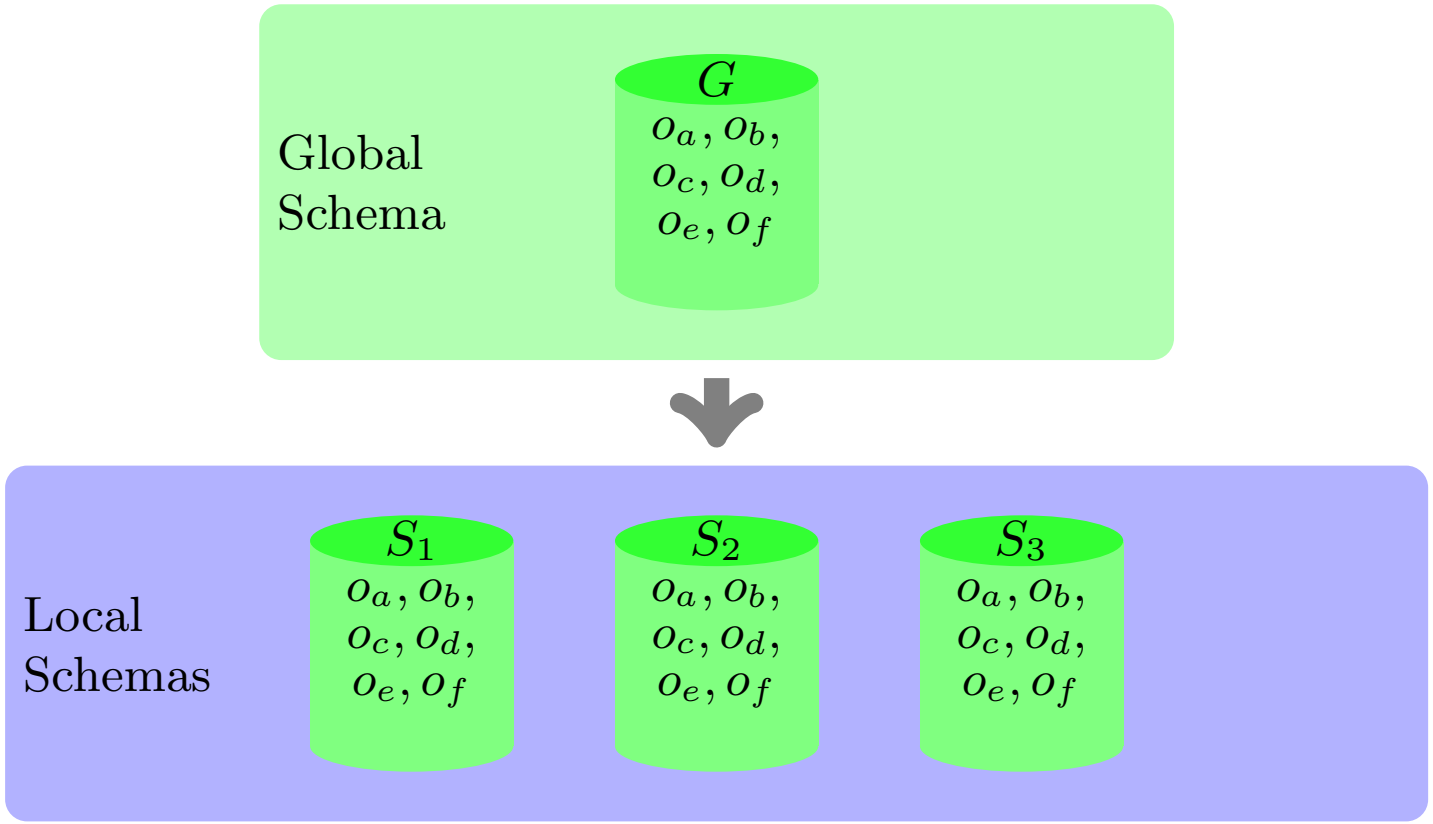
S_2

RDB: Hybrid Fragmentation



$$\text{account}_1 = \pi_{\text{no,type,rate,sortcode}}(\sigma_{\text{type}=\text{current}}\text{account})$$
$$\text{account}_2 = \pi_{\text{no,type,rate,sortcode}}(\sigma_{\text{type}\neq\text{current}}\text{account})$$
$$\text{account}_3 = \pi_{\text{no,cname}}(\sigma_{\text{type}=\text{current}}\text{account})$$
$$\text{account}_4 = \pi_{\text{no,cname}}(\sigma_{\text{type}\neq\text{current}}\text{account})$$

Data Distribution: Replication



replication

- copy data objects $o_a, o_b, \ldots$ of R between sites
- queries may run on any site
  $r[o_a], r[o_b], r[o_c] \rightarrow r[o_a], r[o_b], r[o_c]$ on S_1 (or on S_2 or on S_3)
- updates write on all sites
  $r[o_a], w[o_a] \rightarrow r[o_a], w[o_a]$ on S_1, and $w[o_a]$ on S_2 and S_3

Quiz 4: Speed and Reliability of Replication: Reads

account				
no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

```
SELECT  no
FROM    account
WHERE   cname LIKE 'McBrien%'
```

Considering queries like those above, if account is replicated on several sites, compared with a single site version, is the DDB

A

Faster
Less Reliable

B

Faster
More Reliable

C

Slower
Less Reliable

D

Slower
More Reliable

Quiz 5: Speed and Reliability of Replication: Writes

account				
no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

```
UPDATE  account
SET     rate=2.0
WHERE   type='deposit'
```

Considering queries like those above, if account is replicated on several sites, compared with a single site version, is the DDB

A

Faster
Less Reliable

B

Faster
More Reliable

C

Slower
Less Reliable

D

Slower
More Reliable

Data Distribution: Migration