Index Suggestion In Peloton

Priyatham Bollimpalli
Sivaprasad Sudhir
Vamshi Reddy Konagari
Infrastructure

- We have access to the query history table, stats, etc. at the brain end which can be used by the optimizer.
What’s in the brain??

- Brain job - scheduled every $\triangle$ seconds.
- Index selection Job
- Algorithm bases its cost on the optimizer cost model
- Suggested configuration installed through RPC

An Efficient, Cost-Driven Index Selection Tool for Microsoft SQL Server, Surajit Chaudhuri, Vivek Narasayya. VLDB Very Large Data Bases Endowment Inc. August 1, 1997
Index Selection Algorithm

**SELECT** *
FROM FOO
WHERE b = 7;

**SELECT** *
FROM FOO
WHERE b = 9 and c = 10;

**SELECT** *
FROM FOO
WHERE a = 1 and b = 2 and c = 3;

**SELECT** *
FROM FOO
WHERE c = 1 and b = 1 and a = 3;

**SELECT** *
FROM FOO
WHERE d = 7;

**SELECT** *
FROM FOO
WHERE d = 9 and e = 10;

**SELECT** *
FROM FOO
WHERE d = 1 and e = 2 and f = 3;

**Best Indexes?**

\{ \{a\}, \{b, a\}, \{b, c\} \}

**Parameters?**

```
#indexes?
#columns in each index?
```
Index Selection Algorithm

SELECT * FROM FOO WHERE b = 7;
SELECT * FROM FOO WHERE b = 9 and c = 10;
SELECT * FROM FOO WHERE a = 1 and b = 2 and c = 3;
SELECT * FROM FOO WHERE c = 1 and b = 1 and a = 3;
SELECT * FROM FOO WHERE d = 7;
SELECT * FROM FOO WHERE d = 9 and e = 10;
SELECT * FROM FOO WHERE d = 1 and e = 2 and f = 3;

Best Indexes?

{ {a}, {b, a}, {b, c} }

Parameters?

#indexes k = 2
#columns in each index n = 3
Index Selection Algorithm

SELECT * FROM FOO WHERE b = 7;
SELECT * FROM FOO WHERE b = 9 and c = 10;
SELECT * FROM FOO WHERE a = 1 and b = 2 and c = 3;
SELECT * FROM FOO WHERE c = 1 and b = 1 and a = 3;
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Some candidates to start with
Index Selection Algorithm

Some candidates to start with

```sql
SELECT * FROM FOO WHERE b = 7;
SELECT * FROM FOO WHERE b = 9 and c = 10;
SELECT * FROM FOO WHERE a = 1 and b = 2 and c = 3;
SELECT * FROM FOO WHERE c = 1 and b = 1 and a = 3;
SELECT * FROM FOO WHERE d = 7;
SELECT * FROM FOO WHERE d = 9 and e = 10;
SELECT * FROM FOO WHERE d = 1 and e = 2 and f = 3;
```
Index Selection Algorithm

Some candidates to start with

\{ 
  \{a\}, \{b\}, \{c\},
  \{d\}, \{e\}, \{f\}
\}
Index Selection Algorithm

\[
\begin{align*}
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad b = 7; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad b = 9 \quad \text{and} \quad c = 10; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad a = 1 \quad \text{and} \quad b = 2 \quad \text{and} \quad c = 3; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad c = 1 \quad \text{and} \quad b = 1 \quad \text{and} \quad a = 3; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad d = 7; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad d = 9 \quad \text{and} \quad e = 10; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad d = 1 \quad \text{and} \quad e = 2 \quad \text{and} \quad f = 3; \\
\end{align*}
\]
Index Selection Algorithm

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\text{SELECT} \ \ast \ \text{FROM} \ FOO \ \text{WHERE} \ b = 7;
\]
\[
\text{SELECT} \ \ast \ \text{FROM} \ FOO \ \text{WHERE} \ b = 9 \ \text{and} \ c = 10;
\]
\[
\text{SELECT} \ \ast \ \text{FROM} \ FOO \ \text{WHERE} \ a = 1 \ \text{and} \ b = 2 \ \text{and} \ c = 3;
\]
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\text{SELECT} \ \ast \ \text{FROM} \ FOO \ \text{WHERE} \ c = 1 \ \text{and} \ b = 1 \ \text{and} \ a = 3;
\]
\[
\text{SELECT} \ \ast \ \text{FROM} \ FOO \ \text{WHERE} \ d = 7;
\]
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\text{SELECT} \ \ast \ \text{FROM} \ FOO \ \text{WHERE} \ d = 9 \ \text{and} \ e = 10;
\]
\[
\text{SELECT} \ \ast \ \text{FROM} \ FOO \ \text{WHERE} \ d = 1 \ \text{and} \ e = 2 \ \text{and} \ f = 3;
\]

\[\text{AI} = \{\{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\}\}\]

\[\text{CI} = \{\{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\}\}\]

Need to choose \(k\) indexes from these
Index Selection Algorithm

AI = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}

Need to choose k indexes from these

Naively enumerate and choose the best one from all subsets of size < k?
Index Selection Algorithm

Admissible Index Generation

CI = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}

Need to choose k indexes from these

AI = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}

#indexes?
#columns in each index?
#naive enumeration threshold?

SELECT * FROM FOO WHERE b = 7;
SELECT * FROM FOO WHERE b = 9 and c = 10;
SELECT * FROM FOO WHERE a = 1 and b = 2 and c = 3;
SELECT * FROM FOO WHERE c = 1 and b = 1 and a = 3;
SELECT * FROM FOO WHERE d = 7;
SELECT * FROM FOO WHERE d = 9 and e = 10;
SELECT * FROM FOO WHERE d = 1 and e = 2 and f = 3;
SELECT * FROM FOO WHERE d = 7;
SELECT * FROM FOO WHERE d = 9 and e = 10;
SELECT * FROM FOO WHERE d = 1 and e = 2 and f = 3;
Index Selection Algorithm

$\text{SELECT } * \text{ FROM } \text{FOO WHERE } b = 7;$
$\text{SELECT } * \text{ FROM } \text{FOO WHERE } b = 9 \text{ and } c = 10;$
$\text{SELECT } * \text{ FROM } \text{FOO WHERE } a = 1 \text{ and } b = 2 \text{ and } c = 3;$
$\text{SELECT } * \text{ FROM } \text{FOO WHERE } c = 1 \text{ and } b = 1 \text{ and } a = 3;$
$\text{SELECT } * \text{ FROM } \text{FOO WHERE } d = 7;$
$\text{SELECT } * \text{ FROM } \text{FOO WHERE } d = 9 \text{ and } e = 10;$
$\text{SELECT } * \text{ FROM } \text{FOO WHERE } d = 1 \text{ and } e = 2 \text{ and } f = 3;$

$\text{CI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}$

Need to choose $k$ indexes from these

$\text{AI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}$

#indexes $k = 2$
#columns in each index $m = 3$
#naive enumeration threshold $n = 1$
Index Selection Algorithm

\[
\begin{align*}
\text{AI} &= \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \} \\
\text{CI} &= \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}
\end{align*}
\]

Naively enumerate all subsets of size $< n$ and choose the best one from it
Index Selection Algorithm

\[
\begin{align*}
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad b = 7; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad b = 9 \text{ and } c = 10; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad a = 1 \text{ and } b = 2 \text{ and } c = 3; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad c = 1 \text{ and } b = 1 \text{ and } a = 3; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad d = 7; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad d = 9 \text{ and } e = 10; \\
\text{SELECT} & \quad \text{FROM} \quad \text{FOO} \quad \text{WHERE} \quad d = 1 \text{ and } e = 2 \text{ and } f = 3;
\end{align*}
\]

\(\text{AI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \} \)

\(\text{CI} = \{ \{\}, \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \} \)

Naively enumerate all subsets of size < n and choose the best one from it.
Index Selection Algorithm

\[
\text{SELECT} \ast \text{FROM} \ FOO \ \text{WHERE} \ b = 7; \\
\text{SELECT} \ast \text{FROM} \ FOO \ \text{WHERE} \ b = 9 \ \text{and} \ c = 10; \\
\text{SELECT} \ast \text{FROM} \ FOO \ \text{WHERE} \ a = 1 \ \text{and} \ b = 2 \ \text{and} \ c = 3; \\
\text{SELECT} \ast \text{FROM} \ FOO \ \text{WHERE} \ c = 1 \ \text{and} \ b = 1 \ \text{and} \ a = 3; \\
\text{SELECT} \ast \text{FROM} \ FOO \ \text{WHERE} \ d = 7; \\
\text{SELECT} \ast \text{FROM} \ FOO \ \text{WHERE} \ d = 9 \ \text{and} \ e = 10; \\
\text{SELECT} \ast \text{FROM} \ FOO \ \text{WHERE} \ d = 1 \ \text{and} \ e = 2 \ \text{and} \ f = 3; \\
\]

\[\text{AI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \} \]

\[\text{CI} = \{ \{b\} \} \]

We need 2 indexes
Index Selection Algorithm

AI = { {a}, {b}, {c}, {d}, {e}, {f} }

CI = { {b} }

Greedily choose the next best
Index Selection Algorithm

**Admissible Index Generation**

\[ \text{SELECT * FROM } \text{FOO WHERE } b = 7; \]
\[ \text{SELECT * FROM } \text{FOO WHERE } b = 9 \text{ and } c = 10; \]
\[ \text{SELECT * FROM } \text{FOO WHERE } a = 1 \text{ and } b = 2 \text{ and } c = 3; \]
\[ \text{SELECT * FROM } \text{FOO WHERE } c = 1 \text{ and } b = 1 \text{ and } a = 3; \]
\[ \text{SELECT * FROM } \text{FOO WHERE } d = 7; \]
\[ \text{SELECT * FROM } \text{FOO WHERE } d = 9 \text{ and } e = 10; \]
\[ \text{SELECT * FROM } \text{FOO WHERE } d = 1 \text{ and } e = 2 \text{ and } f = 3; \]

\[ \text{AI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \} \]

\[ \text{CI} = \{ \{b\} \} \]

Greedily choose the next best
Index Selection Algorithm

\[
\begin{align*}
&\text{SELECT } * \text{ FROM FOO WHERE } b = 7; \\
&\text{SELECT } * \text{ FROM FOO WHERE } b = 9 \text{ and } c = 10; \\
&\text{SELECT } * \text{ FROM FOO WHERE } a = 1 \text{ and } b = 2 \text{ and } c = 3; \\
&\text{SELECT } * \text{ FROM FOO WHERE } c = 1 \text{ and } b = 1 \text{ and } a = 3; \\
&\text{SELECT } * \text{ FROM FOO WHERE } d = 7; \\
&\text{SELECT } * \text{ FROM FOO WHERE } d = 9 \text{ and } e = 10; \\
&\text{SELECT } * \text{ FROM FOO WHERE } d = 1 \text{ and } e = 2 \text{ and } f = 3;
\end{align*}
\]

\[
\begin{align*}
&\text{AI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \} \\
&\text{CI} = \{ \{b\}, \{a\} \} \\
&\quad \{ \{b\}, \{c\} \} \\
&\quad \{ \{b\}, \{d\} \} \\
&\quad \{ \{b\}, \{e\} \} \\
&\quad \{ \{b\}, \{f\} \} \\
&\text{CI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}
\end{align*}
\]

Greedily choose the next best
Index Selection Algorithm

AI = { {a}, {b}, {c}, {d}, {e}, {f} }

CI = { {b}, {a} }  
  { {b}, {c} }  
  { {b}, {d} }  
  { {b}, {e} }  
  { {b}, {f} }  

Greedily choose the next best
Index Selection Algorithm

\[
\begin{align*}
\text{AI} &= \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \} \\
\text{CI} &= \{ \{b\}, \{d\} \}
\end{align*}
\]
Index Selection Algorithm

AI = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}

CI = \{ \{b\}, \{d\} \}

Multi-column indexes?
Index Selection Algorithm

AI = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}

CI = CI U (CI x AI)

CI = \{ \{b\}, \{d\} \}

SELECT * FROM FOO WHERE b = 7;
SELECT * FROM FOO WHERE b = 9 and c = 10;
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SELECT * FROM FOO WHERE c = 1 and b = 1 and a = 3;
SELECT * FROM FOO WHERE d = 7;
SELECT * FROM FOO WHERE d = 9 and e = 10;
SELECT * FROM FOO WHERE d = 1 and e = 2 and f = 3;

Admissible Index Generation

Configuration Enumeration

Multi-column indexes?
Index Selection Algorithm

AI = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}

CI = CI \cup (CI \times AI)

\text{SELECT } \ast \text{ FROM } FOO \text{ WHERE } b = 7;
\text{SELECT } \ast \text{ FROM } FOO \text{ WHERE } b = 9 \text{ and } c = 10;
\text{SELECT } \ast \text{ FROM } FOO \text{ WHERE } a = 1 \text{ and } b = 2 \text{ and } c = 3;
\text{SELECT } \ast \text{ FROM } FOO \text{ WHERE } c = 1 \text{ and } b = 1 \text{ and } a = 3;
\text{SELECT } \ast \text{ FROM } FOO \text{ WHERE } d = 7;
\text{SELECT } \ast \text{ FROM } FOO \text{ WHERE } d = 9 \text{ and } e = 10;
\text{SELECT } \ast \text{ FROM } FOO \text{ WHERE } d = 1 \text{ and } e = 2 \text{ and } f = 3;

CI = \{ \{b\}, \{d\} \}

CI = \{ \{b\}, \{d\}, \{ba\}, \{bc\}, \{bd\}, \{be\}, \{bf\}, \{da\}, \{db\}, \{dc\}, \{de\}, \{df\} \}
Index Selection Algorithm

AI = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}

\[ CI = CI \cup (CI \times AI) \]
Index Selection Algorithm

AI = { {a}, {b}, {c}, {d}, {e}, {f} }

CI = {
    {b}, {d},
    {ba}, {bc}, {bd}, {be}, {bf},
    {da}, {db}, {dc}, {de}, {df},
}
Index Selection Algorithm

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\begin{align*}
&\text{SELECT } * \text{ FROM } \text{FOO WHERE } b = 7; \\
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\end{align*}
\]

\[\text{AI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}\]

\[
\begin{align*}
&\text{CI} = \{ \\
&\quad \{b\}, \{d\}, \\
&\quad \{ba\}, \{bc\}, \{bd\}, \{be\}, \{bf\}, \\
&\quad \{da\}, \{db\}, \{dc\}, \{de\}, \{df\}, \\
&\}\}
\end{align*}
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Index Selection Algorithm

$$\text{SELECT } * \text{ FROM FOO WHERE } b = 7;$$
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$$\text{AI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}$$

$$\text{CI} = \{ \{b\}, \{d\}, \{ba\}, \{bc\}, \{bd\}, \{be\}, \{bf\}, \{da\}, \{db\}, \{dc\}, \{de\}, \{df\}, \}$$
Index Selection Algorithm

```sql
SELECT * FROM FOO WHERE b = 7;
SELECT * FROM FOO WHERE b = 9 and c = 10;
SELECT * FROM FOO WHERE a = 1 and b = 2 and c = 3;
SELECT * FROM FOO WHERE c = 1 and b = 1 and a = 3;
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```

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AI = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}
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CI = \{ \{b\}, \{d\}, \{ba\}, \{bc\}, \{dc\}, \{de\}, \{df\} \}
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Index Selection Algorithm

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\text{AI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}
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Index Selection Algorithm

```
SELECT * FROM FOO WHERE b = 7;
SELECT * FROM FOO WHERE b = 9 and c = 10;
SELECT * FROM FOO WHERE a = 1 and b = 2 and c = 3;
SELECT * FROM FOO WHERE c = 1 and b = 1 and a = 3;
SELECT * FROM FOO WHERE d = 7;
SELECT * FROM FOO WHERE d = 9 and e = 10;
SELECT * FROM FOO WHERE d = 1 and e = 2 and f = 3;
```

\[ AI = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \} \]
Index Selection Algorithm

AI = { {a}, {b}, {c}, {d}, {e}, {f} }
Index Selection Algorithm

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\begin{align*}
\text{SELECT} & \ast \text{ FROM } \text{FOO WHERE } b = 7; \\
\text{SELECT} & \ast \text{ FROM } \text{FOO WHERE } b = 9 \text{ and } c = 10; \\
\text{SELECT} & \ast \text{ FROM } \text{FOO WHERE } a = 1 \text{ and } b = 2 \text{ and } c = 3; \\
\text{SELECT} & \ast \text{ FROM } \text{FOO WHERE } c = 1 \text{ and } b = 1 \text{ and } a = 3; \\
\text{SELECT} & \ast \text{ FROM } \text{FOO WHERE } d = 7; \\
\text{SELECT} & \ast \text{ FROM } \text{FOO WHERE } d = 9 \text{ and } e = 10; \\
\text{SELECT} & \ast \text{ FROM } \text{FOO WHERE } d = 1 \text{ and } e = 2 \text{ and } f = 3; \\
\end{align*}
\]

\[
\text{AI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}
\]
Index Selection Algorithm

$$\text{AI} = \{ \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\} \}$$
Testing Framework

- We wrote extensive tests to ensure the correctness of the index selection algorithm and what if index API.
- Found many bugs cost model/optimizer.
- Wrote a generic framework for creating workloads useful for Brain Index Suggestion algorithms.
- Then we thought of running the benchmarks...
Fixes, fixes and fixes...
- TPCC - throughput 9 queries/sec with or without indexes
- Statement cache not flushed on index creation
- Index creation takes ages (on string, floats columns)
- Analyze stats is not used by anyone - crashes on using it for the second time concurrently.
- Optimizer never considered multi-column indexes
- Optimizer - explicitly have to call Analyze stats - which segfaults if you call twice
- TPCC without primary keys segfaults.
- Prepared statements were not being logged
TPC-C Throughput

Workload: TPCC

**Without Indexes**: No primary or secondary indexes

**With DBA Indexes**: Primary and secondary indexes in the workload

**With Brain Indexes**: Start with no indexes and use the indexes suggested by our algorithm
Number of tuples accessed

**TPCC - # Tuples Read**

- Without Indexes: 200,000
- With DBA Indexes: 150,000
- With Brain Indexes: 100,000

**TPCC - # Tuples Read (log)**

- Without Indexes: 8
- With DBA Indexes: 6
- With Brain Indexes: 4
Optimizer Cost

TPCC - Optimizer Cost

Optimizer Cost

Without Indexes | With DBA Indexes | With Brain Indexes
---|---|---
0 | 80000000 | 60000000
40000000 | 20000000 | 0

TPCC - Optimizer Cost (log)

Optimizer Cost (log)

Without Indexes | With DBA Indexes | With Brain Indexes
---|---|---
4 | 8 | 3
6 | 7 | 5

Algorithm Runtime - Number of queries

Number of Queries in Index Selection

- #indexes = 10
- #columns = 2
- #naive enumeration threshold = 2
Algorithm Runtime - Naive enumeration threshold

Naive Enumeration Threshold in Index Selection

#indexes = 10
#columns = 3
#queries = 2000
Algorithm Runtime - Number of indexes chosen

Number of Indexes Chosen in Index Selection

- #columns = 3
- #naive enumeration threshold = 2
- #queries = 1000
Algorithm Runtime - Number of columns / iterations

Multi-column Index Generation in Index Selection

- #indexes = 10
- #naive enumeration threshold = 2
- #queries = 1000
Future Work

- Tuning the knobs
- Incorporate memory usage of the indexes created
- Online version
Thanks :)

Questions?