Transactional Consistency and Automatic Management in an Application Data Cache

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Modern web applications face immense scaling challenges

increasingly complex, personalized content

e.g. Facebook, MediaWiki, LiveJournal...

Existing caching techniques are less useful

whole-page caches: foiled by personalization

database caches: more processing is being done in the application layer
Application-Level Caching
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e.g. memcached, Java object caches
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very lightweight in-memory caches

stores application objects (computations), i.e.:
not a database replica
not a query cache
Why Cache Application Data?

Cache higher-level data closer to app needs:
  DB queries, complex structures, HTML fragments

Can separate common and customized content

Reduces database load
Reduces application server load
  • this matters too (application servers aren’t cheap!)
Existing Caches Add To Application Complexity

No transactional consistency
- violates guarantees of the underlying DB
- app. code must deal with transient anomalies

Hash table interface leaves apps responsible for:
- naming and retrieving cache entries
- keeping cache up-to-date (invalidations)
Harder Than You Think!

Naming: cache key must uniquely identify value

- MediaWiki stored list of recent changes with same key regardless of # days requested (#7541)

Invalidations: require reasoning globally about entire application

- After editing wiki page, what to invalidate?
Harder Than You Think!

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Invalidations: require reasoning globally about entire application

- After editing wiki page, what to invalidate?
- Forgot editor’s User object – contains edit count (#8391)
Introducing TxCache

Our cache provides:

- **transactional consistency**: serializable, point-in-time view of data, whether from cache or DB
- **bounded staleness**: improves hit rate for applications that accept old (but consistent) data
- **simpler interface**: applications mark functions cacheable; TxCache caches their results, including naming and invalidations
- TxCache library hides complexity of cache management
- Integrates with new cache server, minor DB modifications (Postgres; <2K lines changed)
- Together, ensure whole-system transactional consistency
**TxCache Interface**

- `beginRO(staleness)`, `commit()`, `beginRW()`, `abort()`

- `make-cacheable(fn)`
  where `fn` is a side-effect-free function that depends only on its arguments and the database state

  ➔ `fn` returns cached result of previous call with same inputs if still consistent w/ DB
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That’s it.
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That’s it.
Really!
Outline

1. Application-Level Caching
2. TxCache Interface
3. Ensuring Transactional Consistency
4. Automating Invalidations
5. Evaluation
Consistency Approach

Goal: all data seen in a transaction reflects single point-in-time snapshot

• Assign timestamp to transaction

• Know the validity interval of each object in cache or database: set of timestamps when it was valid

• Then: transaction can read data if data’s validity interval contains txn’s timestamp
A Versioned Cache

Cache entries tagged with validity intervals

- each entry one immutable version of an object
- allows lookup for value valid at certain time
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Staleness

Assign transaction an earlier timestamp

• if consistent with application requirements
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Requires starting a DB transaction at same timestamp

• internally, snapshot isolation supports this
• added interface to expose this to cache library
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Validity of a tuple
= timestamps of creating, deleting transactions
  • multiversion DBs already track this
Computing Query Validity

\[ x \quad y \quad z \quad q \]

\[ \text{time} \]

40 45 50
Computing Query Validity

inserted by txn #41

\( x \)

\( y \)

\( z \)

\( q \)

\[ \text{time} \]

\[ 40 \quad 45 \quad 50 \]
Computing Query Validity

- inserted by txn #41
- deleted by txn #50

- x
- y
- z
- q

40 45 50  

Tuesday, October 5, 2010
Computing Query Validity

\[ \text{SELECT } * \text{ FROM . . .;} \]
Computing Query Validity

\[
\text{SELECT } * \text{ FROM ...;}
\]
\[
\text{result} = \{x, y\}
\]
Computing Query Validity

Intersect validity intervals of tuples accessed

\[
\text{SELECT} \ * \ \text{FROM} \ ...; \\
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\]
Computing Query Validity

Intersect validity intervals of tuples accessed

```
SELECT * FROM ...;
result = {x, y}
VALIDITY [41, 48)
```
Lazy Timestamp Selection

Hard to choose timestamp *a priori*

- Don’t know access pattern or cache contents
- **Insight:** don’t have to choose right away!
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Invalidations

What about objects that are still valid?

- don’t know their upper validity bound yet!
- represent as open-ended validity intervals

Later, database notifies cache if object changes; cache truncates interval
Invalidation Tags

How to identify which objects changed?

- DB doesn’t know which app-level objects are cached

Objects in cache have *invalidation tags*

- Modified DB to assign invalidation tags to each query
- DB generates list of tags affected by each update
- Cache finds affected objects and updates interval
Invalidation Tags

Inval. tags come from query’s access methods

- `TABLE:KEY=VALUE` for queries that use index lookups
- `TABLE:*` for non-indexed queries (rare)

```
SELECT * FROM users WHERE name = 'floyd';
[result]

INVALIDATION TAGS users:name=floyd
```
Invalidation Stream

On each update, DB generates affected tags:
- for each tuple affected, one tag per index key

Broadcasts to all cache nodes
- ordered stream, with transaction timestamps

Cache lookups treat unbounded intervals as bounded at last timestamp received
- avoids invalidate & lookup race conditions
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Evaluation

• How much benefit from adding caching?
• Does using stale data help?
• Does consistency hurt performance?
RUBiS Benchmarks

RUBiS: simulated eBay-like auction site

- standard browsing & bidding workload; 85% read-only
- two datasets: 850 MB (in-memory), 6 GB (disk-bound)

All servers 2x 3.20 GHz Xeon, 2 GB RAM

- 1 DB server (modified Postgres 8.2.11)
- 9 frontend/cache servers (Apache 2 / PHP 5)
Cache Performance
(in-memory DB; 2 cache nodes)

Max throughput (requests/sec)

Cache hit rate

Cache size

Max throughput:
- 64MB
- 256MB
- 512MB
- 768MB
- 1024MB

Cache hit rate:
- 0%
- 20%
- 40%
- 60%
- 80%
- 100%
Cache Performance
(disk-bound DB; 8 shared web/cache nodes)

Max throughput (requests/sec)

Cache hit rate
Even A Little Staleness Helps

Relative throughput vs. Staleness limit in seconds

- TxCache (in-memory DB)
- TxCache (disk-bound DB)
- no caching (baseline)

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### Costs of Consistency

Cache misses classified as:

- **compulsory**: data never seen
- **staleness**: data invalidated & too old to use
- **capacity**: data was evicted
- **consistency**: data available but inconsistent w/ prior reads

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<thead>
<tr>
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<tbody>
<tr>
<td>in-memory, 512 MB, 30 s stale</td>
<td>7.8%</td>
</tr>
<tr>
<td>in-memory, 512 MB, 15 s stale</td>
<td>5.4%</td>
</tr>
<tr>
<td>in-memory, 64 MB, 30 s stale</td>
<td>0.2%</td>
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common to other caches
Costs of Consistency

Verified experimentally by disabling consistency: transaction can read any data valid in last 30 sec
Related Work

Application-level caches:
- more flexible than whole-page caches: partial results
- require explicit management by application
- no transactional support (e.g. memcached) or transactions only within cache (e.g. JBoss, AppFabric)

Database replication:
- FAS, Ganymed: keep stale replicas with batched updates
- can’t apply methods to app-level caching
Conclusion

TxCache: application-layer caching with a simpler programming model

- provides transactional consistency across both cache and database
- automatic management: applications not responsible for lookups, updates, invalidations

New mechanisms:
- consistency ensured by tracking object validity intervals
- automatic database-generated invalidations

Consistency imposes little performance cost