hochschule mannheim

Understanding Eventual Consistency

MSI Presentation SS2014

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Introduction

„...the storage system guarantees that if no new updates are made to the object, eventually all accesses will return the last updated valuee“
–W. Vogels (2009)

Introduction

Interpretations of Eventual Consistency

Interpretation 1:

> *"When you read data[...], the response might not reflect the results of a recently completed write operation. The response might include some stale data. Consistency across all copies of the data is usually reached within a second; so if you repeat your read request after a short time, the response returns the latest data."*

Interpretation 2:

> *"This sort of system we term "single writer eventual consistency". So what are its properties?*
> *(1) A client could read stale data. (2) The client could see out-of-order write operations. [...] So this is our weakest form of consistency - eventually consistent with out of order reads in the short term."*

DynamoDB Documentation

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MongoDB Documentation

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> *(2)The client could see out-of-order write operations.[...]*
> *So this is our weakest form of consistency - eventually consistent with* **out of order reads** *in the short term."*

The Problem

- Disparate and low-level formalisms
  consistency model is tied to system implementation
- Weak guarantees
  in realistic scenarios updates **never** *stop*
- Conflict resolution policies
  resolution of conflicts in multiple replicas
- Combinations of different consistency levels
  strong consistency may be needed at certain times

$\Rightarrow$ Some sort of formalism is needed to define semantics of Eventual Consistency

Agenda

1. Replicated Data Types

2. Axiomatic Specification Framework

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- Two examples: Int Register **intreg**, Counter **ctr**

$$\mathrm{Op}_{\mathrm{ctr}} = \{\mathrm{rd}, \mathrm{inc}\}$$
$$\mathrm{Op}_{\mathrm{intreg}} = \{\mathrm{rd}, \mathrm{wr}(k) | k \in \mathbb{Z}\}$$

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(e.g. $\sigma = \{\mathrm{rd\ rd\ wr(5)\ wr(6)\ rd}\}$ or $\sigma = \{\mathrm{rd\ rd\ inc\ inc\ rd}\}$)

Replicated Data Types

Sequential Data Type Specification

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S_{\mathrm{intreg}}(\sigma \ \mathrm{wr}(k)) &= S_{\mathrm{ctr}}(\sigma \ \mathrm{inc}) = \perp;
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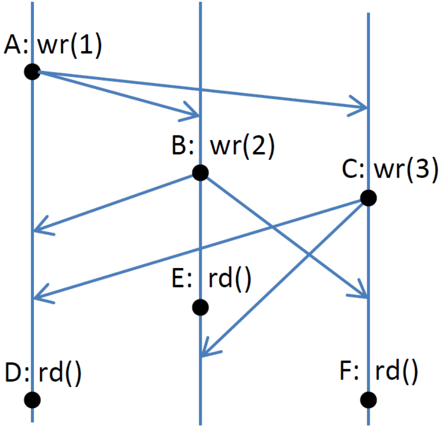
Replicated Data Types

Semantics of Eventual Consistency

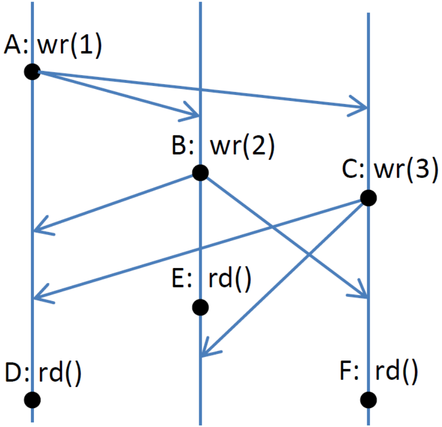
- semantics of eventually consistent systems are harder to formalize
- concurrent operations on the same object happen on multiple replicas
- each replica executes operations immediately, updating other replicas later
- different implementation strategies for replicated data types



A: wr(1)
B: wr(2)
C: wr(3)
E: rd()
D: rd()
F: rd()

Replicated Data Types

Conflict Resolution Strategies



1. Make concurrent operations commutative

Replicated Data Types

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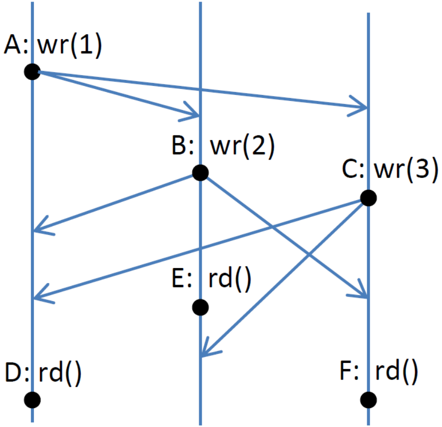

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2. Order concurrent operations

Replicated Data Types

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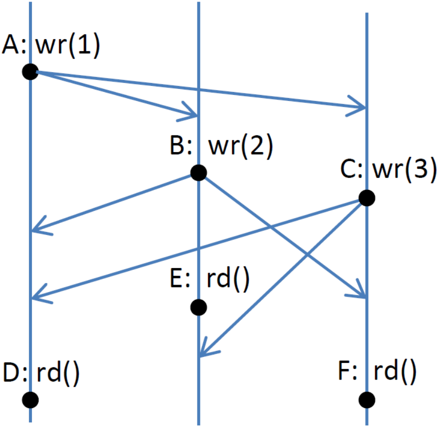

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Replicated Data Types

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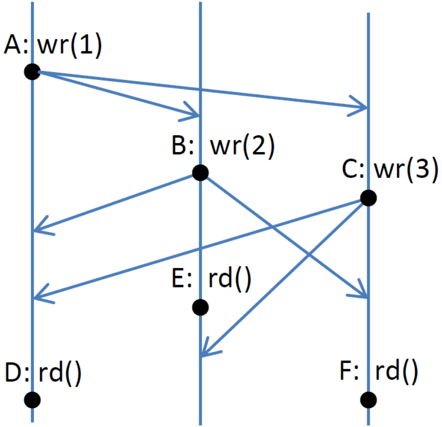

1. Make concurrent operations commutative
2. Order concurrent operations
3. Flag conflicts (let the user decide)
4. Resolve conflicts semantically

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Replicated Data Types

Replicated Data Type Specification

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$$u \xrightarrow{\mathrm{ar}} v, \mathrm{ar} \subseteq V \times V$$

Example: Strategy **Make Concurrent Calls Commutative**

$$F_{\text{ctr}}(\text{inc}, V, \text{vis}, \text{ar}) = \perp;$$
$$F_{\text{ctr}}(\text{rd}, V, \text{vis}, \text{ar}) = (\text{the number of inc operations in } V);$$

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Example: Strategy **Order Concurrent Operations**

$$F_{\mathrm{intreg}}(\mathrm{inc}, V, \mathrm{vis}, \mathrm{ar}) = S_{\mathrm{intreg}}(V^{\mathrm{ar}} f)$$

Axiomatic Specification Framework

Session and Action

- clients wish to perform operations in a common context
- **sessions** provide a way to track client identity for operations
- an **action** is a tuple $(e, s, [x.f : k])$
  - e: unique identifier
  - s: session id $\in \mathrm{SId}$
  - $[x.f : k]$: object, operation and return value

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Example:

$$a = (1af3c, 17, [x.rd : k]);\ \mathrm{type}(x) = \mathrm{intreg}$$

Axiomatic Specification Framework

History and Execution

- the set of all actions that happen in a database is denoted as Act
- a **history** (A, so) is a set of actions $A \subseteq \mathrm{Act}$ and a **session order** relation $\mathrm{so} \subseteq A \times A$
- an **execution** $X = (A, \mathrm{so}, \mathrm{vis}, \mathrm{ar})$ enhances the history with visibility and arbitration relations
- we can now extract an operation context for any action in any session, providing a deterministic return value

Axiomatic Specification Framework

Levels of Eventual Consistency

- With these replicated data types we can define multiple forms of eventual consistency
  - Basic eventual consistency
  - Ordering guarantees
  - On-demand consistency strengthening
- Every form contains multiple axioms

Axiomatic Specification Framework

Basic Eventual Consistency Axioms

- Axioms a database implementation has to apply to offer basic eventual consistency
- Well-Formedness Axioms
  - SOwf, ARwf, VISwf
- Data Type Axiom
  - RVAL
- Basic Eventual Consistency axioms
  - EVENTUAL
  - THINAIR

Axiomatic Specification Framework

Session guarantees

- Axioms that ensure that databases stay consistent within a single session with a client
- !RYW!, MR, WYRV, WFRA, MWV, MWA

Axiomatic Specification Framework

Causal Consistency Axioms

- POCV, POCA, COCV, COCA

Conclusion

- the paper provides a way to **precisely specify eventually consistent systems** in a common notation
- **every aspect of a system is covered**, from data types to client interaction
- specifications are **independent of implementation details**
- still **very theoretical**, no tools available to map between specifications and implementation
- the framework is **not suitable for programmers**, as it is very abstract and not easily understandable and applicable

Discussion