PUTTING CONSISTENCY BACK INTO EVENTUAL CONSISTENCY

Valter Balegas, Sérgio Duarte, Carla Ferreira, Rodrigo Rodrigues, Nuno Preguiça
NOVA LINCS / U. Nova de Lisboa

Mahsa Najafzadeh, Marc Shapiro
INRIA, LIP6

INTERNET SERVICES NOWADAYS

- Services operate on a global scale.
- An unprecedented number of people are using internet services.
enroll(Pac-man, A)

enroll(Mario, A)

removeTournament(A)
Mario is enrolled in a tournament that was concurrently removed.
IS COORDINATION NEEDED?

- \text{enroll}(\text{Mario, A})
- \text{enroll}(\text{Pac-man, A})
- \text{removeTournament}(A)

Ordering of operations:
- \text{enroll}(\text{Mario, A})
- \text{enroll}(\text{Pac-man, A})
- \text{removeTournament}(A)

OUTLINE

- Background
- Explicit Consistency
- Indigo
- Evaluation
- Conclusion

EXPLICIT CONSISTENCY

- Programmer specifies application invariant.

- System ensures that every state transition preserves the invariant.

- Opportunity to improve performance by not restricting execution ordering.

A METHODOLOGY FOR EXPLICIT CONSISTENCY

- Identify \textit{I-offenders}
  - Static analysis identifies operations that may break invariants when executed concurrently.

- Choose reservations
  - Efficient mechanism to execute \textit{I-offenders} avoiding coordination.

- Instrument application code with selected mechanism.
A METHODOLOGY FOR EXPLICIT CONSISTENCY

• Identify I-offenders
  – Static analysis identifies operations that may break invariants when executed concurrently.

• Choose reservations
  – Efficient mechanism to execute I-offenders avoiding coordination.

• Instrument application code with selected mechanism.

STATIC ANALYSIS: ALGORITHM

\[ \text{Inv} = \text{enrolled}(p, t) \Rightarrow \text{player}(p) \land \text{tournament}(t) \]

\[ \text{Inv} = \text{true} \Rightarrow \text{player}(p) \land \text{tournament}(t) \]

\[ \text{Inv} = \text{true} \Rightarrow \text{false} \]

Inv = enrolled(p, t) ⇒ false

Use SMT Solver to test all pairs of operations.

STATIC ANALYSIS: APPLICATION MODEL

• Programmer specifies:
  – Invariant:
    “Players can only participate in existing tournaments.”

  \[ \text{Inv} = \text{enrolled}(p, t) \Rightarrow \text{player}(p) \land \text{tournament}(t) \]

  – Operations’ side effects:
    enroll (p,t): \{\text{enrolled}(p,t) := \text{true}\}
    removeTournament(t): \{\text{tournament}(t) := \text{false}\}
**RESERVATIONS**

- Mechanisms to control the execution of *I-offenders* without breaking invariants.
- Coordination outside the operation flow.
- Different reservations for different invariants:

<table>
<thead>
<tr>
<th>Invariant type</th>
<th>Reservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic</td>
<td>Multi-level Lock</td>
</tr>
<tr>
<td>Numeric</td>
<td>Escrow</td>
</tr>
<tr>
<td>Referential Integrity</td>
<td>Multi-level Lock</td>
</tr>
<tr>
<td>Uniqueness</td>
<td>UID Generator</td>
</tr>
<tr>
<td>Disjunction</td>
<td>Multi-level Mask</td>
</tr>
<tr>
<td>Range partition</td>
<td>Partition Lock</td>
</tr>
</tbody>
</table>

**RESERVATIONS: MULTI-LEVEL LOCK**

- Protects the execution of conflicting operations.
- Only allow the execution of one type of operation at a time.
- Operation can be executed by multiple clients that hold the lock.

**RESERVATIONS: EXAMPLE**

- Tournament A vs. Tournament B
- Player Sonic vs. Pac-man vs. Mario
- DC1 vs. DC2

ENROLL(\(*,A\))

ENROLL(\(*,A\))

enroll(Pac-man, A)
enroll(Pac-man, A)

enroll(Mario, A)

removeTournament(A)
**RESERVATIONS: EXAMPLE**

![Image of RESERVATIONS example]

- Player: Sonic, Pac-man, Mario
- Tournament: A, B
- DC1, DC2

---

**INDIGO**

- Middleware that provides Explicit consistency on top of KV-Stores.
- Requires only properties that are known to be efficient.
- Can be extended with new reservations.

**EVALUATION**

- How well does the system scale?
- What is the latency of operations?
- Behavior with more reservations per operation?
- Applicability of the solution.

**DEPLOYMENT**

- Data-centers deployed in AWS:
  - 3 Regions (EU, US-EAST/WEST);
  - N app-servers connect to local DBs;
  - Clients submit operations to the app-server in close loop.
- Compare performance:
  - Causal Consistency
  - Strong Consistency (Writes to single server)
  - Red-Blue Consistency (Causal + Writes to single server)
  - Explicit Consistency (Causal + Reservations)
CONCLUSIONS

- Explicit Consistency successfully reduces coordination:
  - Programmers provide simple annotations;
  - Static analysis detects conflicting operations;
  - Low-latency operations with reservations.

- Performance comparable to Causal consistency.
QUESTIONS?

Latency over time

(c) Latency of individual operations of US-W datacenter (ad counter application).

Overhead with increasing contention

(a) Peak throughput with increasing contention (ad counter application).

(b) Peak throughput with an increasing number of invariants (ad counter application).

Adding more reservations

Indigo R5-W1
Indigo R6-W1
Indigo R6-W3
Weak R5-W1
Weak R5-W2
Weak R5-W3