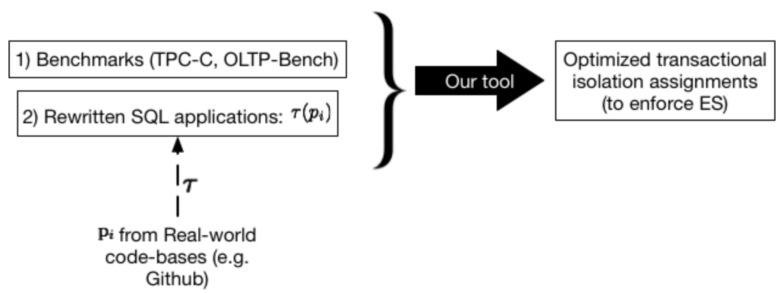
# 1 Evaluation

In this section, we will present results from our empirical studies and experiments showing the practicality of eventual consistency (ES) as a notion of correctness for applications derived from two main sources. Additionally, we will show how naive enforcement of ES (or any other notion of correctness) will result in loss of either performance or correctness and we will consequently present our provably correct and optimized database isolation requirements for a corpus of real-world and theoretical applications.

## 1.1 Benchmark and real-world applications




The above figure shows the outline of our analysis. In order to show usability of our tool, we performed an extensive study of SQL programs, including (but not limited to) eCommerce, banking, warehouse management, all derived from either of the following two sources:

**i) Benchmark applications:** We gathered a large set (about 10) of benchmark applications that are all widely used for industrial or academic prototype benchmarking. Detailed descriptions of these applications are publicly available and there is a consensus in the database community on their *correct behavior* (in some cases, e.g. TPC-C, the applications level invariants are explicitly specified).

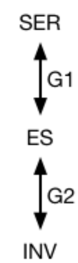
**ii) Real-world applications:** In addition to the above benchmarks, we also gathered a corpus of popular Ruby-on-Rails applications from Github and analyzed them using our tool. Since our general-purpose analysis tool targets generic database-backed applications as opposed to any specific development framework, we had to transfer the Rails applications into simpSQL.

In order to facilitate this process, we created a (to be precise, expanded an already existing) tool to execute Rails applications symbolically and create an equal simpSQL program which then we were able to analyze using our tool. The transformation is shown by $\tau$ in the above figure and is fairly straightforward (although we do not present any formal proof of equivalence for $p$ and $\tau(p)$).

## 1.2 Evaluation of ES as a notion of correctness

In this section, we will present emprical evidence supporting our choice of ES as the right notion of application correctness.

Specifically, we will first show that, ES preserves *all (high-level) invariants* that programmers need (i.e. it is not too weak in practice). Second, we will show that ES is not too strong; that is:




1. G1 gap is not too small, i.e. there is a considerable number of cases where SER is violated but ES is not.
2. G2 gap is not unnecessarily big, i.e. we inspect all cases where ES is violated but invariants are not, and we argue that there are in fact other (arguably important) invariants that are being violated and thus ES is actually helping developers who might forget to specify all of their requirements.

In the following sections, we will consider two classes of invariants: *explicit invariants* (e.g. associations and validations on Rails Active Records) and *implicit invariants*, which are widely discussed and accepted in the literature as requirements for applications (e.g. non-negative inventories and account balances for many eCommerce applications [1]).

### 1.2.1 correctness

Here we will show that ES can be safely used as the notion of correctness for all examined applications. Specifically, we need to show something like the following arguments (the degree of formal rigorousness is debatable for a SIGMOD submission):

1. Given a Rails program $p_r$ and the conjunction of its invariants $INV_r$, the transformation $\tau$ returns *equivalent* SQL program and invariants,

$(p_s, INV_s)$. That is, for any given history $H_r$ of $p_r$ that preserve $INV_r$, there exists a history $H_s$ that is *observably* equal to $H_r$ and preserves $INV_s$.

2. Then we need to show that in all the studied applciations, all SQL histories that preserve $ES$ also presereve $INV_s$.

#### 1.2.2 efficiency

Here we will show how often SER is violated in real-world applications but ES is not. We applied our tool twice on each application (once looking for SER violations and once modified for ES violations) and the following results show that in x% of the transactions are ES-safe under default isolation level of the deployed database but are not SER-safe. (or in another approach, we can show that x% of the transactions are assigned a weaker isolation guarantee when ES is enforced as opposed to SER).

Additionally, by analyzing ES anomalies found by our tool, we report in almost all of them some invariant (explicit or implicit) also being violated. In the rare cases where no invariant is violated, we found critical problems on some objects (objects not specified by the developer in any invariant for example) which we argue that are able to break the whole functionality of the program.

### 1.3 Correctness Enforcement

In this section, we present empirical results on the performance gained by our optimal ES enforcement approach. Our results show y% performance gain over a naive (or default) enforcement technique, where all database transactions are serializable (default). Our tool additionally offers a bounded correctness guarantee, which the following experiment results (with a number of concurrent transactions much higher than the bound) support the claim that is enough to find and fix real-world problematic applications (for example, we can run TPC-C on the default transactions of the database and show invariants are violated, and then by applying our tool and finding the necessary isolation levels, we can run it again with thousands of concurrent clients and show no invariant is violated).

As an additional result, we also show the performance gain from replacing ES with SER as the enforced correctness criteria in a real-world setting.

## 1.4 Comparison to related works

**ACIDRain: Concurrency-Related Attacks on Database-Backed Web Applications[4]:** We share the goal of finding the possibility of anomalous application behaviors on weakly isolated transactions with this paper. However, instead of a simple syntactic analysis, we offer a fully automated tool which captures the semantics of the programs and reports less false alarms (with the addition of the bounded guarantee). For example, in the paper they mention:

> "... the second class of false positives were due to anomalies that were in fact triggerable but were handled by other program logic and thus rendered benign."

Here, we will present our reults showing how our tool is able to detect cases like above and report actual errors more accurately.

**Serializability for Eventual Consistency: Criterion, Analysis, and Applications[2]:** Unlike this paper, we target ES (instead of SER) as the correctness notion which liberates us from manual interactions with the tool such as the folllwings:

> "... For the sake of the experiment, we exclude from our analysis queries issued within declared rendering sections of TOUCHDEVELOP scripts, as they are very frequently executed (every time a page is re-rendered), guaranteed to have no side effects on the program state, and are almost always harmless in practice."

or

> "... Therefore, we chose performance over strong consistency in this case by adding a lightweight annotation to exclude the queries in the above figure from the serializability checking. With similar reasoning, we can resolve several other violations."

**Feral Concurrency Control: An Empirical Investigation of Modern Application Integrity[1]:** Similar to [4], here also they perform a simple syntactic analysis on the programs and thus are prone to false errors. In addition, their tool is specifically designed for Rails applications while ours is supporting a generic SQL language which can be used for all database backed applications. Finally, we do not consider high-level invariants as the notion of correctness, which as we have already shown can be problematic in practice.

**Alone Together: Compositional Reasoning and Inference for Weak Isolation[3]:** They do not offer any evidence of the applicability of their tool in practice, while we have extensive study results using our fully automated tool (maybe we need a better argument here...)

# References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