Checking Non-Deterministic Behavior in Unit Tests

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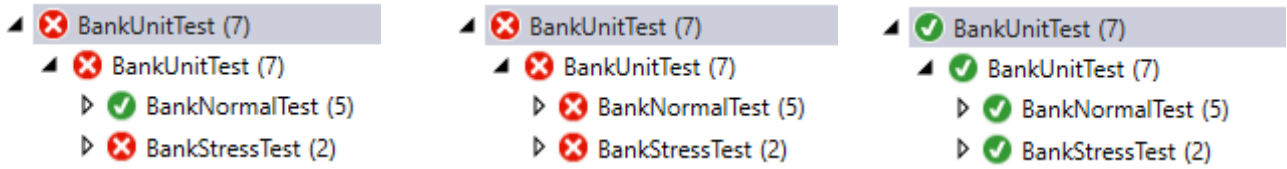
Concurrency is Omnipresent

- Software becomes increasingly concurrent
- Mostly through implicit multi-threading
  - Asynchronous or reactive programming,
  - Task parallelization, thread pools
  - Parallel querying, parallel loops
  - Timers, finalizers etc.

Challenge for Testing

- Non-deterministic execution
  - Issues may only occur in certain schedules
  - Bugs can appear seldom or never in tests
- Consequences
  - Tests sometimes green, sometimes red
  - Unreliable regression testing



Types of Concurrency Errors

- Race conditions
  - Errors because of insufficient synchronization
- Data races
  - Unsynchronized concurrent RW or WW accesses to same variable or array element
- Deadlocks
  - Cyclic lock-and-wait dependencies
- Livelocks
  - Cyclic perpetual wait dependencies (spinning threads)
- Starvation
  - Continuous progress prevention (with chance to recover)

Requires knowledge of program semantics (intended behavior, progress)

Frequent Practitioner's Approach

Concurrent stress tests

- Many threads call operations
- Check assertions at the end
- Insert extra synchronization in tests

+ No extra tools
– Sporadadic occurrence
– Not reproducible
– Code effort

Concurrent Unit Test

```
[TestMethod]
[Timeout(TestTimeout)]
public void TestConcurrentDeposits() {
  const int N = 10;
  var account = new BankAccount();
  var list = new List<Thread>();
  for (int count = 0; count < N; count++) {
    var thread = new Thread(() => account.Deposit(1));
    thread.Start();
    list.Add(thread);
  }
  foreach (var thread in list) {
    thread.Join();
  }
  Assert.AreEqual(N, account.Balance);
}
```

Timeout in case of deadlocks/blocking

Join before assertion

Check final balance (race condition)

Systematic Approaches

- Dynamic analysis (e.g. ThreadSanitizer, Inspector)
  - + Precise
  - - Sporadic occurrence
  - - Not reproducible
- Static analysis (e.g. CHESS, JPF)
  - + Completeness
  - - False positives
  - - State explosion
- Sound + precise in general = halting problem

Hybrid Approaches

- Dynamic + static
  - Run, analyze trace, statically derive alternative traces
  - E.g. Concolic Testing, Predictive Testing

  + Precision

  - Expensive constraint solver
- Systematic concrete interpretation
  - Exhaustive testing towards full schedule coverage
  - E.g. CHESS, JPF

  + Precision

  - State explosion

Goals for Our Checker

- **Extensive**: Analyze many schedules (but not all)
- **Fast**: Few seconds even for large code
- **Reproducible**: Always report the same issues
- **Precise**: Few false warnings

But not complete, may miss issues

Initially designed for use in an IDE

Question: Could it be used for testing as well?

ISSTA 2018 Paper of Checker

Practical Detection of Concurrency Issues at Coding Time

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ABSTRACT

We have developed a practical static checker that is designed to interactively mark data races and deadlocks in program source code at development time. As this use case requires a checker to be both fast and precise, we engaged a simple technique of randomized bounded concrete concurrent interpretation that is experimentally effective for this purpose. Implemented as a tool for C# in Visual Studio, the checker covers the broad spectrum of concurrent language concepts, including task and data parallelism, asynchronous programming, UI dispatching, the various synchronization primitives, monitor, atomic and volatile accesses, and finalizers. Its application to popular open-source C# projects revealed several real issues with only a few false positives.

CCS CONCEPTS

• **Software and its engineering → Concurrent programming structures**; **Software defect analysis**;

current language versions. Static concurrency analysis continues to be an area of research where very few practical tools [26, 36] are on hand. For newer C# versions, there even exists no static checker for data races or deadlocks at all. Previous tools such as CHESS [24] have been discontinued. The situation is discussed in more detail in Section 6.

In this work, we aim to provide a practical tool that detects common concurrency errors in a slightly different setting than other work in this area. This tool should interactively support software developers when working in an integrated development environment (IDE): It should directly highlight problematic program sections with regard to concurrency during the coding. For this purpose, the following checker properties were considered essential:

- **Static**: The source code as displayed in the IDE needs to be analyzed. The code being written can be incomplete or contain erroneous fragments, making a program execution and thus a dynamic analysis impossible.

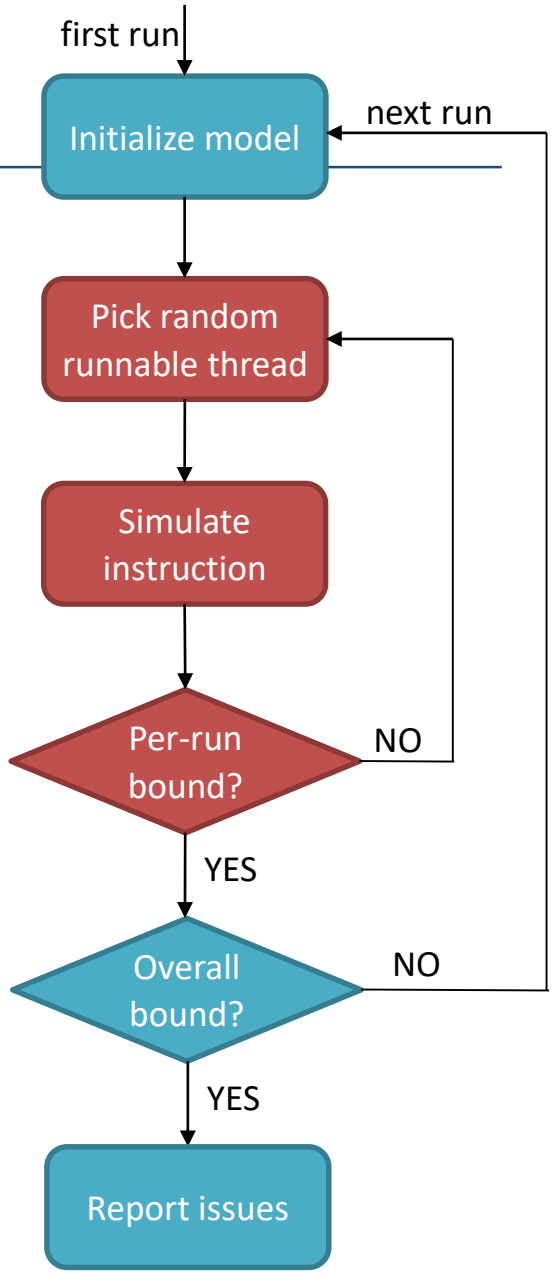
HSR Parallel Checker

- Static checker tool for Visual Studio IDE
- For C#, covering wide concurrency spectrum
  - Tasks, async/await, parallel loops, various sync. constructs, atomics, volatile, finalizers, timers, parallel queries …
  - UI-apps/libraries/unit tests/console-apps
- Downloadable on Visual Studio Marketplace (>2.5k installs)

Approach

Randomized mostly-concrete interpretation

- Map code to internal runtime model
- Simulate execution on this model
- Maintain exact state where possible
- Repeated random scheduling
- Per-run and overall bound
- Report encountered issues
- Vector clock for race detection



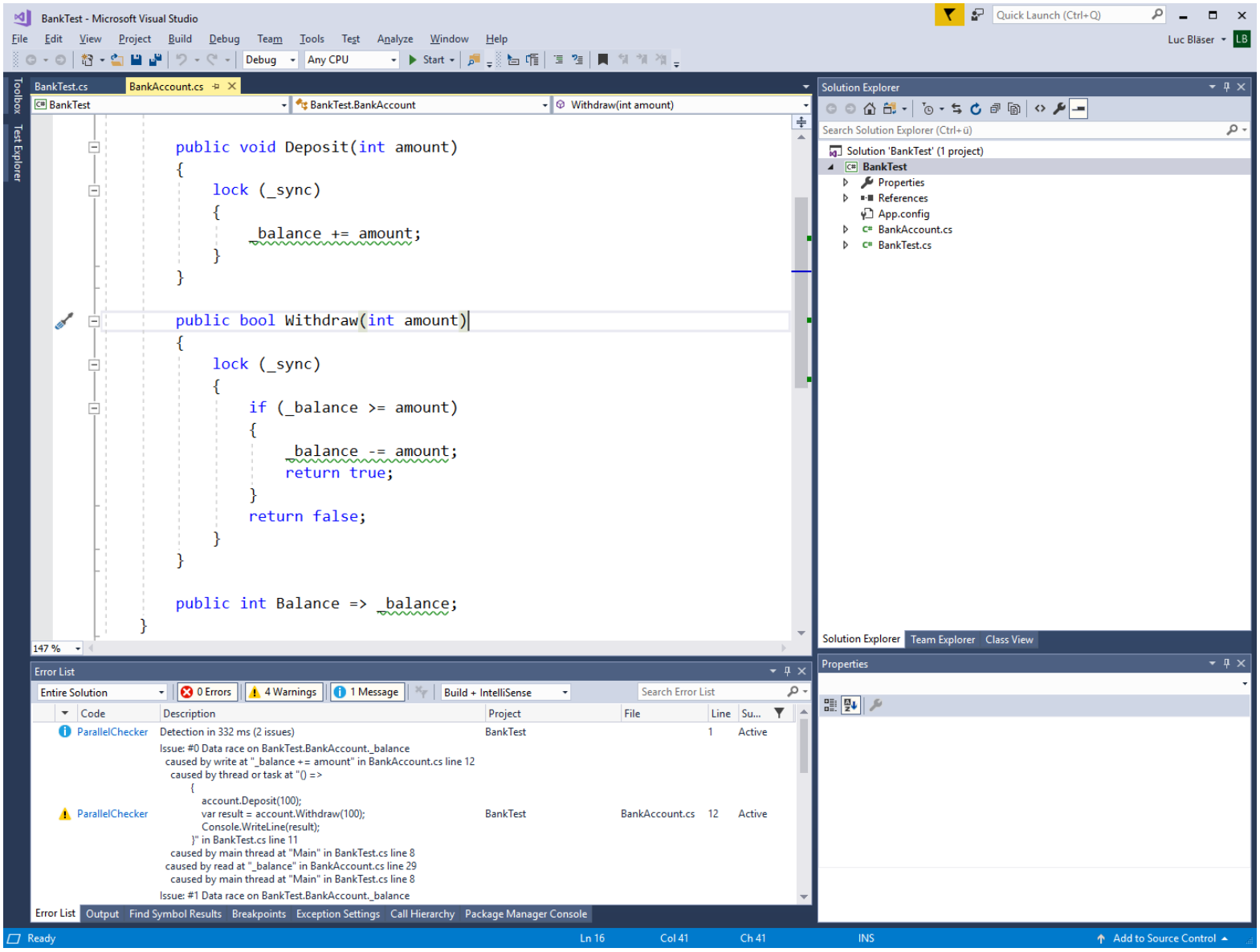
Particular Aspects

- Reproducibility of results
  - Seeded pseudo-random numbers
  - Bounds on logical number of steps and size
- Dynamic technique in static context
  - Does not run the code
  - Code may be incomplete or incorrect
- Deliberately simple design
  - Random scheduling, no constraint solver
  - Examine more code with less sophistication

Abstract States

- Cope with unknown external input
  - Uninterpreted value
  - Imprecise assumptions (branches, locks, thread starts etc.)
  - May result in false positives (and false negatives)
- Today's focus: Unit Tests
  - Full input should be defined, no user interaction
  - Checkers becomes entirely concrete
  - No false positives

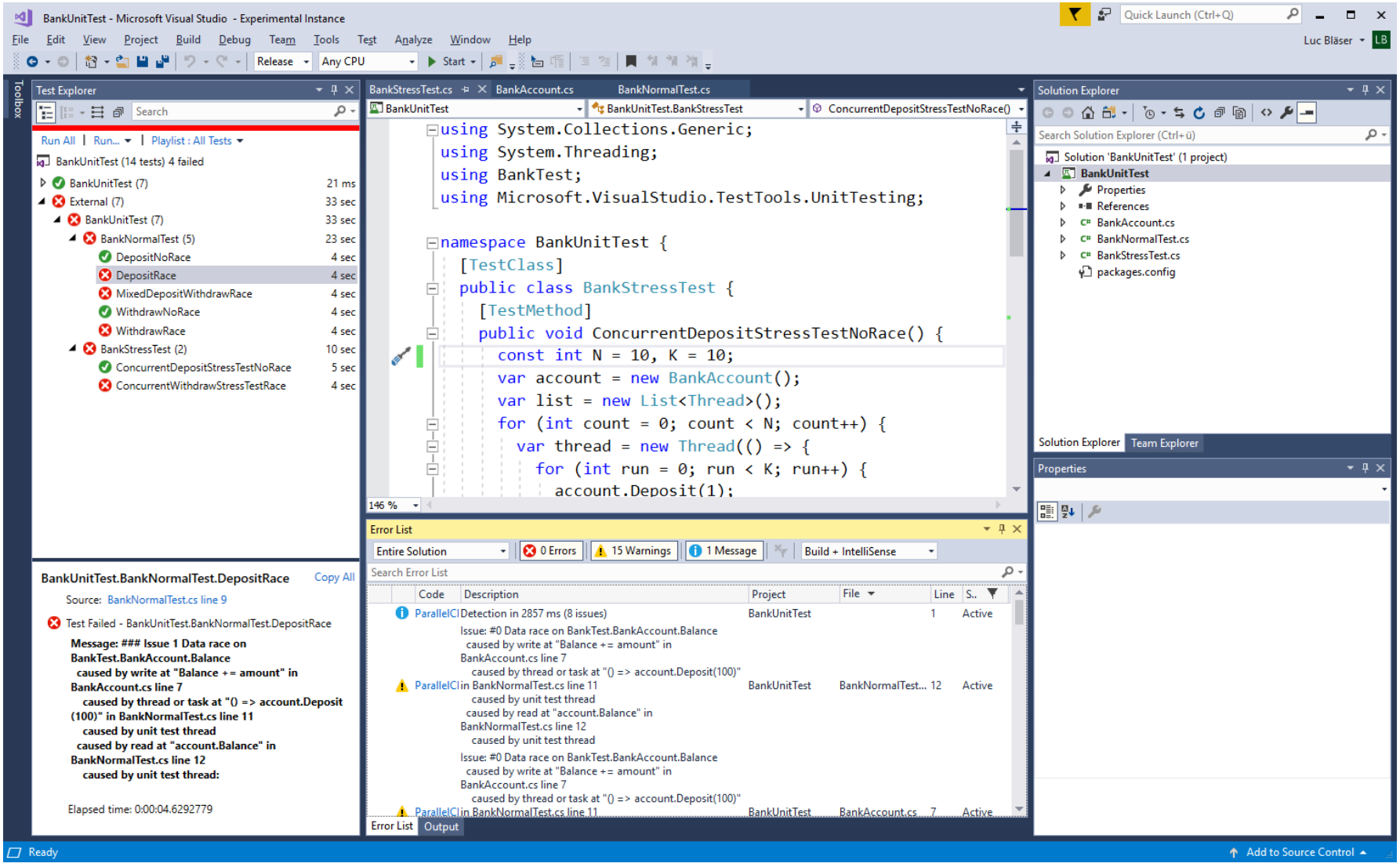
IDE Checker Demo



Application to Testing

- Run checker by opening unit test source
  - Checker uses unit test method as entries
  - See errors in source code in IDE
- Run checker inside unit test framework
  - Run each unit test through the checker
  - See green/red unit test result

Parallel Unit Test Demo



Conclusion

- Testing is difficult – in particular for concurrency
  - Non-deterministic bug occurrence
  - Hard to reproduce, hard to detect at all
- Dynamic testing within static analysis
  - Our checker does this to be precise and reproducible
- Static analysis within dynamic testing
  - Unit tests could again run through the static checker

Thank You for Your Attention!

- **Contact**
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  - lblaeser@hsr.ch, http://concurrency.ch
- **Project Website**
  - http://parallel-checker.com
- **VS Marketplace**
  - https://marketplace.visualstudio.com/items?itemName=LBHSR.HSRParallelCheckerforC7VS2017

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Parallel # Checker

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