Practical Detection of Concurrency Issues at Coding Time

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Motivation

Detect concurrency errors in the IDE

- Interactively mark issues during coding
- Primary focus on data races

Requirements

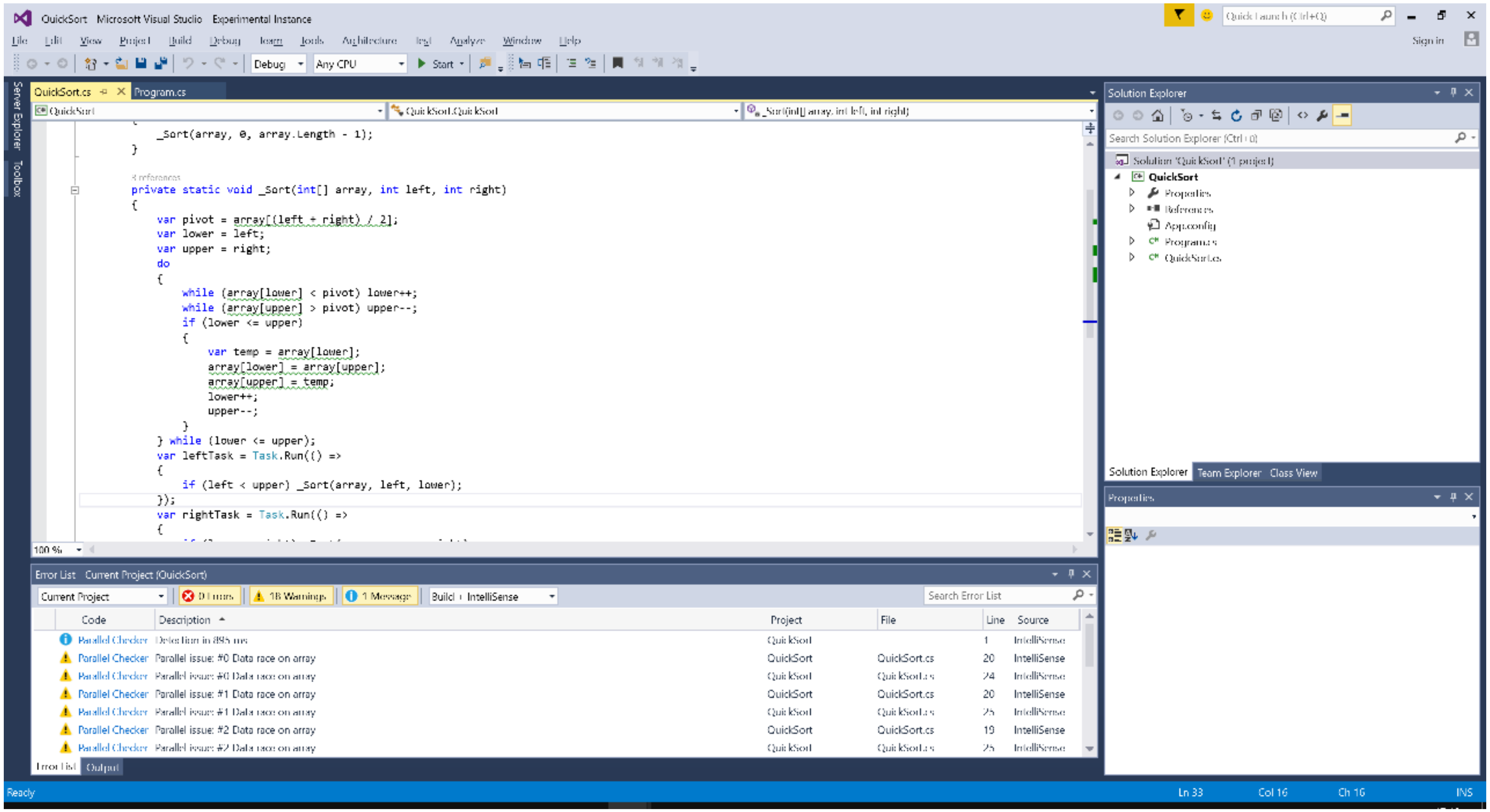
- **Static**: Analyze source code, even if not compileable
- **Fast**: Quick feedbacks within a few seconds
- **Precise**: As few false warnings as possible

Compromise: We may miss issues (incompleteness)

HSR Parallel Checker

- New static checker tool for Visual Studio IDE
- For latest 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)

Brief Demo



```
        _Sort(array, 0, array.Length - 1);
    }

    3 references
    private static void _Sort(int[] array, int left, int right)
    {
        var pivot = array[(left + right) / 2];
        var lower = left;
        var upper = right;
        do
        {
            while (array[lower] < pivot) lower++;
            while (array[upper] > pivot) upper--;
            if (lower <= upper)
            {
                var temp = array[lower];
                array[lower] = array[upper];
                array[upper] = temp;
                lower++;
                upper--;
            }
        } while (lower <= upper);
        var leftTask = Task.Run(() =>
        {
            if (left < upper) _Sort(array, left, lower);
        });
        var rightTask = Task.Run(() =>
        {
```

Error List Current Project (QuickSort)

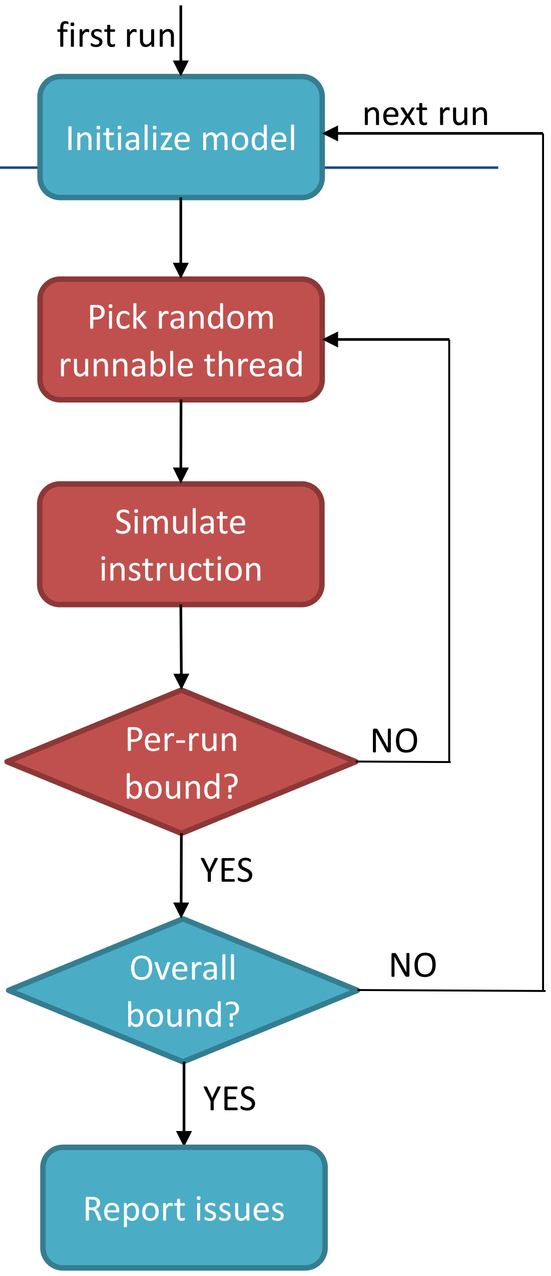
Current Project | 0 Errors | 18 Warnings | 1 Message | Build + IntelliSense

Code	Description	Project	File	Line	Source
Parallel Checker	Detection in 895 ms	QuickSort		1	IntelliSense
Parallel Checker	Parallel issue: #0 Data race on array	QuickSort	QuickSort.cs	20	IntelliSense
Parallel Checker	Parallel issue: #0 Data race on array	QuickSort	QuickSort.cs	24	IntelliSense
Parallel Checker	Parallel issue: #1 Data race on array	QuickSort	QuickSort.cs	20	IntelliSense
Parallel Checker	Parallel issue: #1 Data race on array	QuickSort	QuickSort.cs	25	IntelliSense
Parallel Checker	Parallel issue: #2 Data race on array	QuickSort	QuickSort.cs	19	IntelliSense
Parallel Checker	Parallel issue: #2 Data race on array	QuickSort	QuickSort.cs	25	IntelliSense

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 a 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 input
  - Command line args, user/file input etc.
- Uninterpreted value
  - Stands for any possible value
  - Propagates through expressions
- Imprecise assumptions
  - Take random branch on uninterpreted condition
  - Ignore locks, thread starts/joins on uninterpreted object
  - Do not report data races on uninterpreted addresses

May result in false positives (and false negatives)

Experimental Evaluation

- 10 C# GitHub project by user ranking
- 3 C# GitHub projects, «concurrency» tag
- 402 assemblies
- 3.4 MLOC source code

Project	Lines of Code	Assemblies
Roslyn 15.2	1,851,645	114
SignalR 2.2.2	86,574	31
Nancy 2.0.0	72,345	56
ILSpy 2.4	279,432	14
CefSharp 57.0.0	14,116	9
ReactiveUI 7.4.0	33,381	10
MsBuild 15.1.1012	397,281	20
Hangfire 1.6.14	73,986	12
Polly 5.2.0	91,363	6
NLog 4.4.11	63,381	6
Orleans 1.4.2	137,695	29
Akka.NET 1.2.2	225,744	82
Rx.NET 3.1.1	155,358	13
	3,482,302	**402**

Experimental Results

Analyzed assemblies	402
Analysis time	13 min in total
Time per assembly	1.7 sec on average
Detected issues	121 races
False Positives	14 (12%)
Real issues	107
Productive issues	89
Found in	Roslyn, SignalR, NLog, Rx.NET

Found Races

Roslyn

```
private static int s_delayMilliseconds = 0;

static GCManager() {
   System.Threading.Tasks.Task.Run(() => {
      …
      s_delayMilliseconds = (int)key.GetValue(…);
      …
    });
    …
}

internal static void TurnOffLowLatencyMode() {
  // same for UseLowLatencyModeForProcessingUserInput()
  if (s_delayMilliseconds <= 0) …
  …
}
```

data race

SignalR

```
class Client {
  public static void Main() { …
    if (Arguments.IsController) {
       ControllerHub.Start(Arguments);
    }
    Run().Wait();
  }

  static async Task Run() {
    …
    while (TestPhase != ControllerEvents.Connect) {
      …
    }
    …
  }

  static void OnPhaseChanged(ControllerEvents phase) {
    …
    TestPhase = phase;
    …
  }
}

class ControllerHub {
  internal static void Start(…) {
    … ThreadPool.QueueUserWorkItem(_ => Run());
  }

  static void Run() {
    … RunConnect(); …
  }

  static void RunConnect(){
    … SignalPhaseChange(ControllerEvents.Connect); …
  }

  static void SignalPhaseChange(ControllerEvents phase) {
    … Client.OnPhaseChanged(phase);
  }
}
```

data race

and other issues…

Conclusion

- Concurrency checking at development time
  - Directly warn in IDE when races are programmed
  - Requires to be static, fast, and precise
- Full-fledged implementation for C#
  - Broad concurrency feature spectrum
  - It is the sole static race checker for modern C#
- Simple but experimentally effective approach
  - Applicable to other programming languages

Thank You for Your Attention!

- **Contact**
  - Luc Bläser, HSR Hochschule für Technik Rapperswil
  - 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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