```
Contract.Requires(amount > 0.0);
Contract.Ensures(Balance == Contract.OldValue(Balance) + amount);
Contract.Invariant(Balance > 0.0);
```

Encouraging Effective Contract Specifications

Todd Schiller, Kellen Donohue, Forrest Coward, Michael Ernst

University of Washington

Microsoft Code Contracts

```
public class BankAccount {

    public void Deposit(decimal amount){
        Contract.Requires(amount > 0.0);
        Contract.Ensures(Balance == Contract.OldValue(Balance) + amount);
        . . .
    }

    . . .
}
```

Precondition

Postcondition

- C# Syntax and Typing
- Run-time Checking
- Static Checking

What contracts do developers write?

What contracts *could* developers write?

How do developers react when they are shown the difference?

How can we use this information to make developers more effective?

Developers use contracts ineffectively

- Most contracts check for missing values, e.g. != null
- Miss aspects of program behavior
- Don’t (effectively) use powerful features, e.g., object invariants

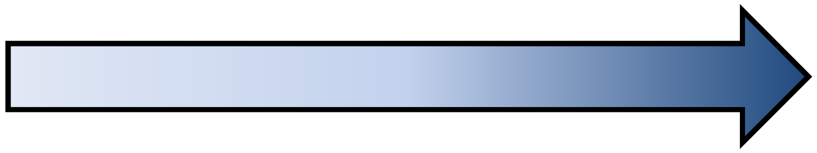
Introduce tooling to reduce annotation burden

Make suggestions key part of tool ecosystem

Curate best practices.
It’s OK to be normative

Goal: Move Developers Toward Using Contracts as Specifications

Contracts as Assertions

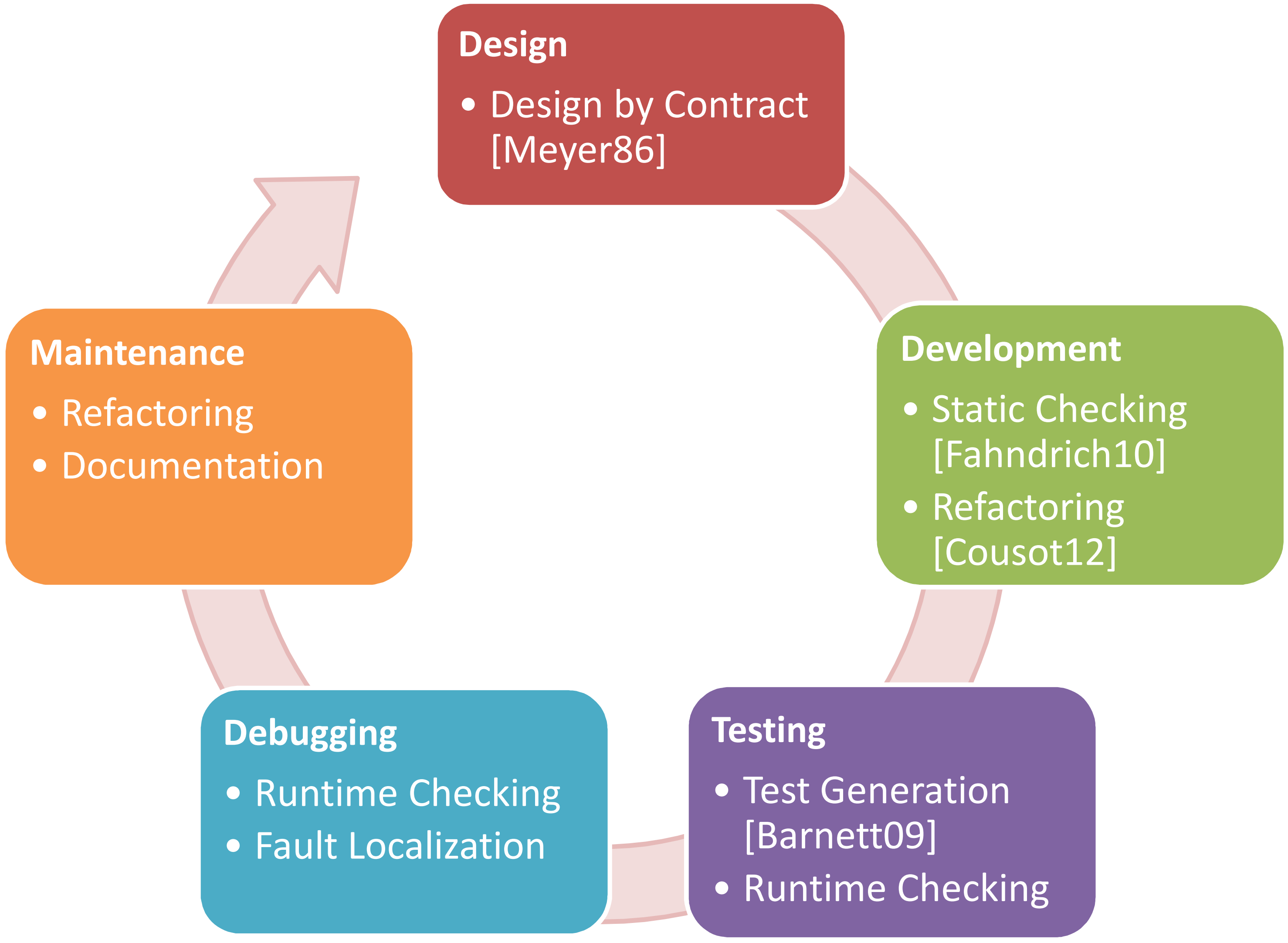


Contracts as Functional Specifications

- Assumption Violations

- What program *should* do
- Object Invariants
- Contracts on Interfaces

Effective Contracts Have Many Benefits



Talk Outline

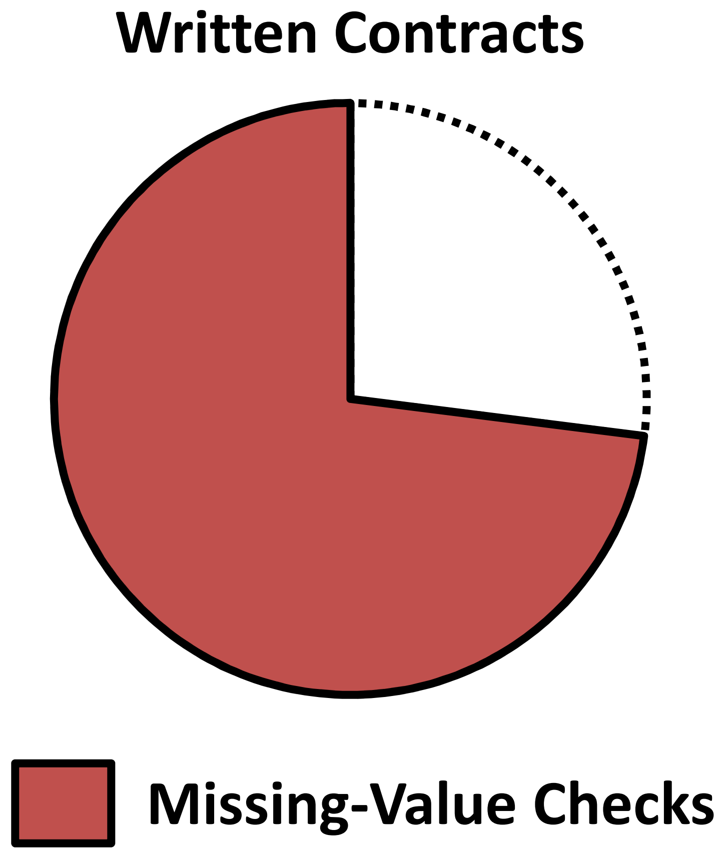
1. The contracts that developers write

2. The contracts that developers *could* write

3. How developers react when shown the difference

Most Contracts Just Check for Missing Values

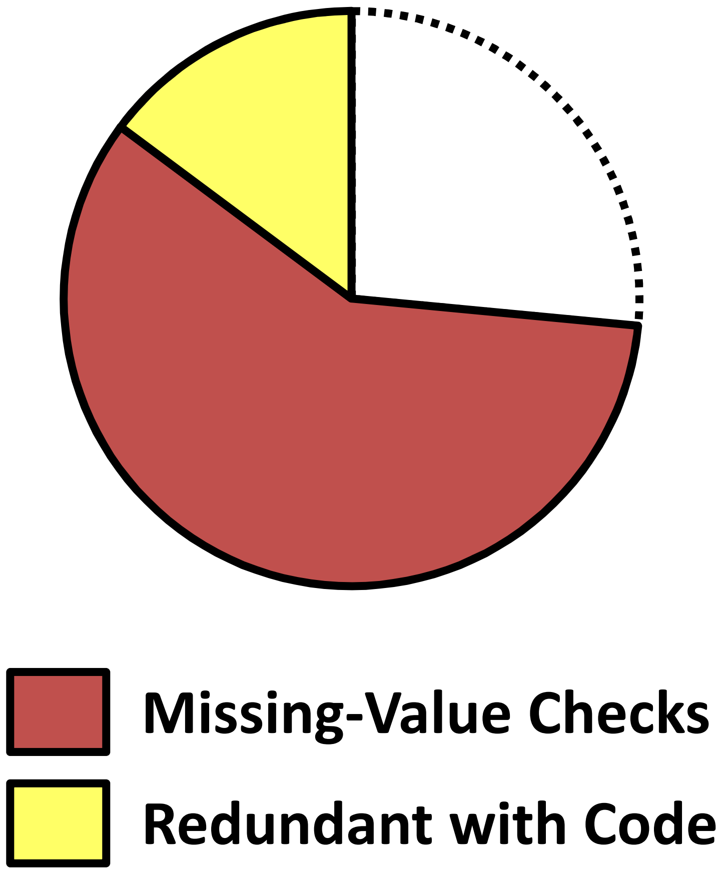
- Subjects: The 90 C# projects with Code Contracts on Ohloh
- Missing-Value: Null, Empty String, Empty Collection



Many Postconditions are Trivially Redundant with the Code

- 25% of contracts are postconditions
- 15% *of postconditions* specify:
  - The value a method returns
  - The value a property is set to

Written Postconditions



Smart Defaults Reduce Annotation Burden

Nullness: Checker Framework [Papi08] for Java assumes parameters and return values are non-null

Tool	Annotations per 1K LOC
Checker Framework w/ Defaults	**1-2 annos.**
Code Contracts	**2-5 annos.**

Defaults cut # of annotations needed in half

Awkward to override restrictions using Contracts:

x != null || x == null

Microsoft Code Contracts

```
public class BankAccount {

    public void Deposit(decimal amount){
        Contract.Requires(amount > 0.0);
        Contract.Ensures(Balance == Contract.OldValue(Balance) + amount);
        . . .
    }

    . . .
}
```

- C# Syntax and Typing
- Run-time Checking
- Static Checking

Why Don’t Developers Use Functional Specifications? They are Expensive

- **Verbose**, especially involving return / pre-state expressions
  - **Contract.Result**<IEnumerable<TEdge>>()
- **High runtime cost**
  - **Contract.ForAll**(collection, elt => elt > 0)
- **No static checking**
  - dictionary[key] < array.Length

Talk Outline

1. The contracts that developers write

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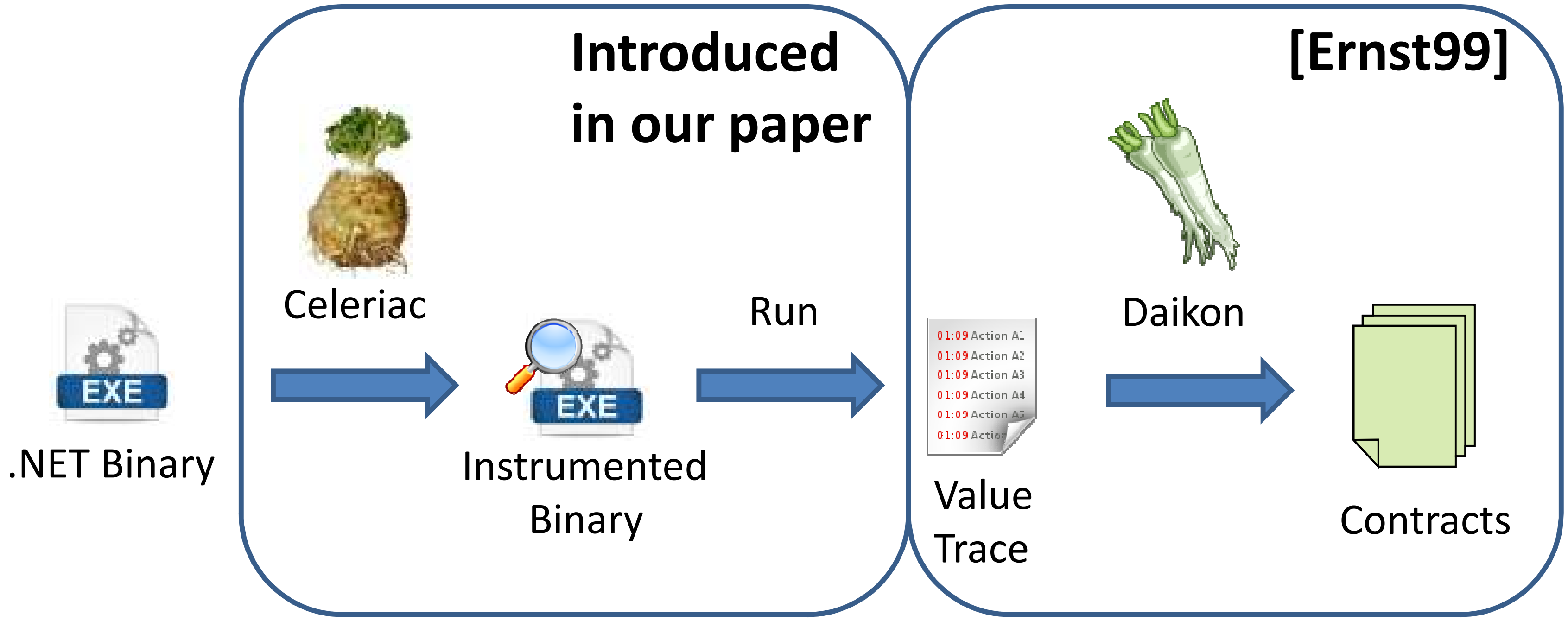
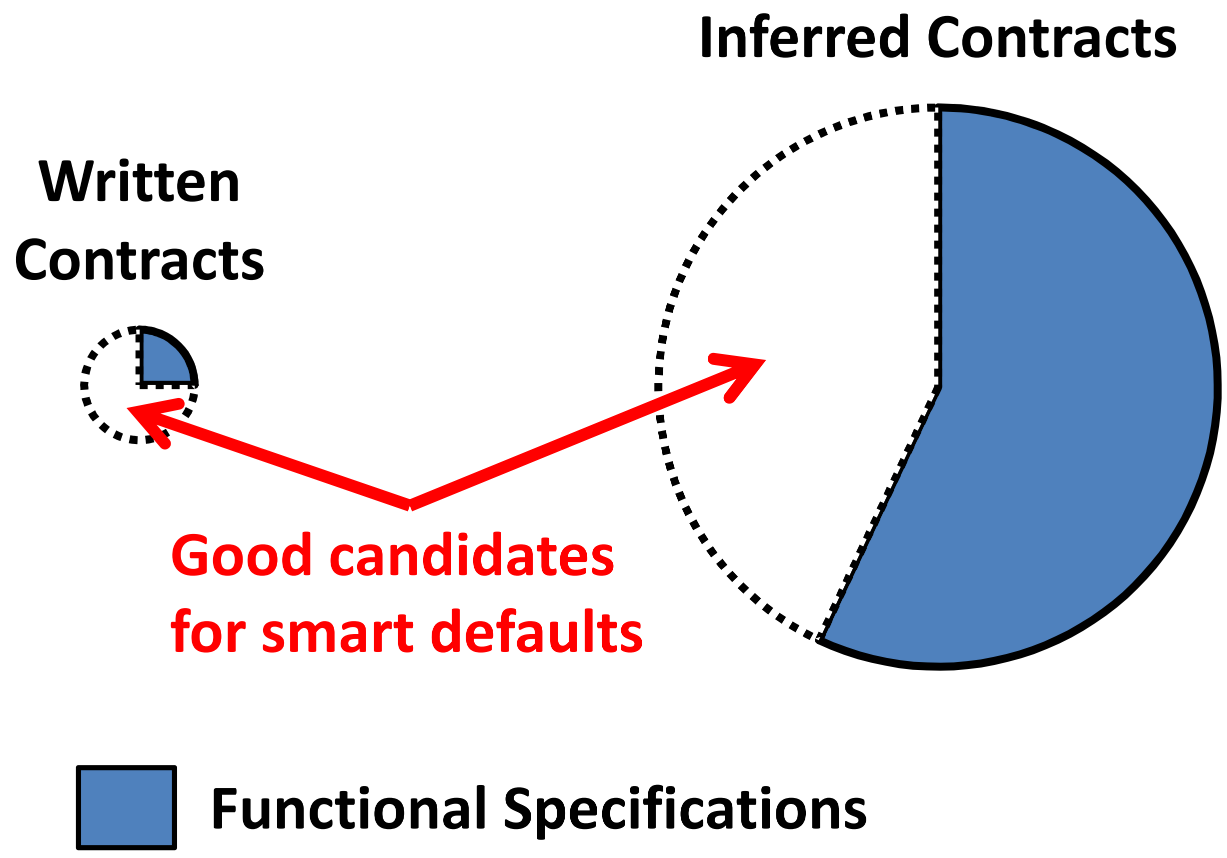
Inferring Contracts From Runtime Traces with Daikon + Celeriac



Celeriac: code.google.com/p/daikon-dot-net-front-end

There's a Gap Between Written Contracts and Program Behavior



Developer-Written Contracts Miss Aspects of Program Behavior

Object State:

- this.IsUsable == (this.Reader.GetRefCount != 0)

Relations:

- this.programElement.ColumnNumber >= 0

State update:

- this.Reader.GetRefCount() >= **Contract.OldValue(**this.Reader.GetRefCount()**)**

Talk Outline

1. The contracts that developers write
2. The contracts that developers *could* write
3. How developers react when shown the difference

Case Study Research Question

How do developers decide which contracts to add if contracts can be added with a single click?

Case Study Methodology

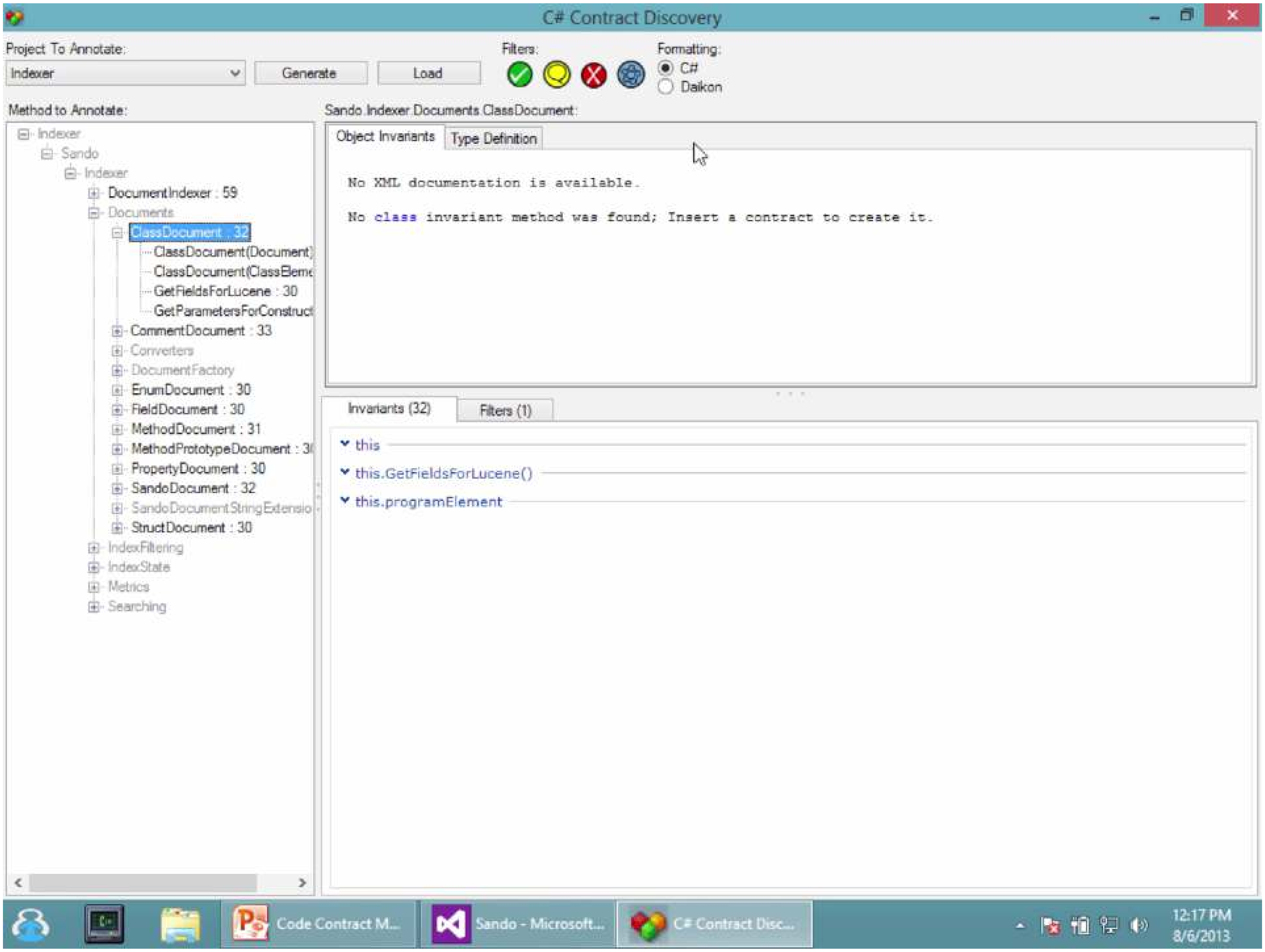
Subjects: two developers and their projects

- Sando Code Search: document indexer component
- Mishra RSS Reader: model component

Existing Contracts:

- 28 contracts across 482 methods
- All but 3 were checks for missing values

Task: Developer used interface to insert inferred contracts



Formatting: [✓ C#] Daikon

```
Indexer
  Sando
    Indexer
      DocumentIndexer : 59
      Documents
        ClassDocument : 32
          ClassDocument(Document)
          ClassDocument(ClassEleme
          GetFieldsForLucene : 30
          GetParametersForConstruct
        CommentDocument : 33
        Converters
        DocumentFactory
        EnumDocument : 30
        FieldDocument : 30
        MethodDocument : 31
        MethodPrototypeDocument : 3
        PropertyDocument : 30
        SandoDocument : 32
        SandoDocumentStringExtensio
        StructDocument : 30
      IndexFiltering
      IndexState
      Metrics
      Searching
```

Sando.Indexer.Documents.ClassDocument:

```
No XML documentation is available.

No class invariant method was found; Insert a contract to create it.
```

```
this
this.GetFieldsForLucene()
this.programElement
```

Case Study Research Question

How do developers decide which contracts to add if contracts can be added with a single click?

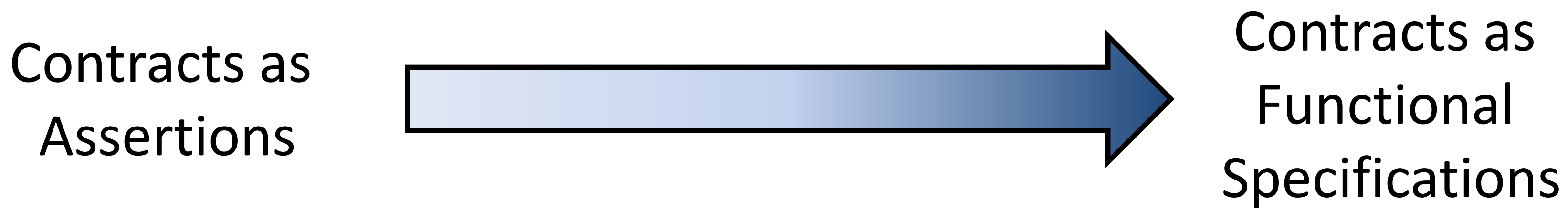
Differing Viewpoints to Inserting Contracts

- Sando: in favor of automatically inserting all contracts above some confidence threshold
- Mishra Reader: chose not to insert many valid contracts
  - Avoiding code bloat
  - Fear of runtime overhead
  - Belief that contracts should only be written at module boundaries (public methods)

Suggestions are Beneficial (Up to a Point)

- Tool suggested types of contracts developers would not have thought of
  - e.g.: `Contract.ForAll(collection, elt => elt > 0)`
- Not a perfect substitute for training
  - Sando developer, unaware of object invariant and interface contracts, overlooked tool's suggestions

Training Affects How Contracts Are Used

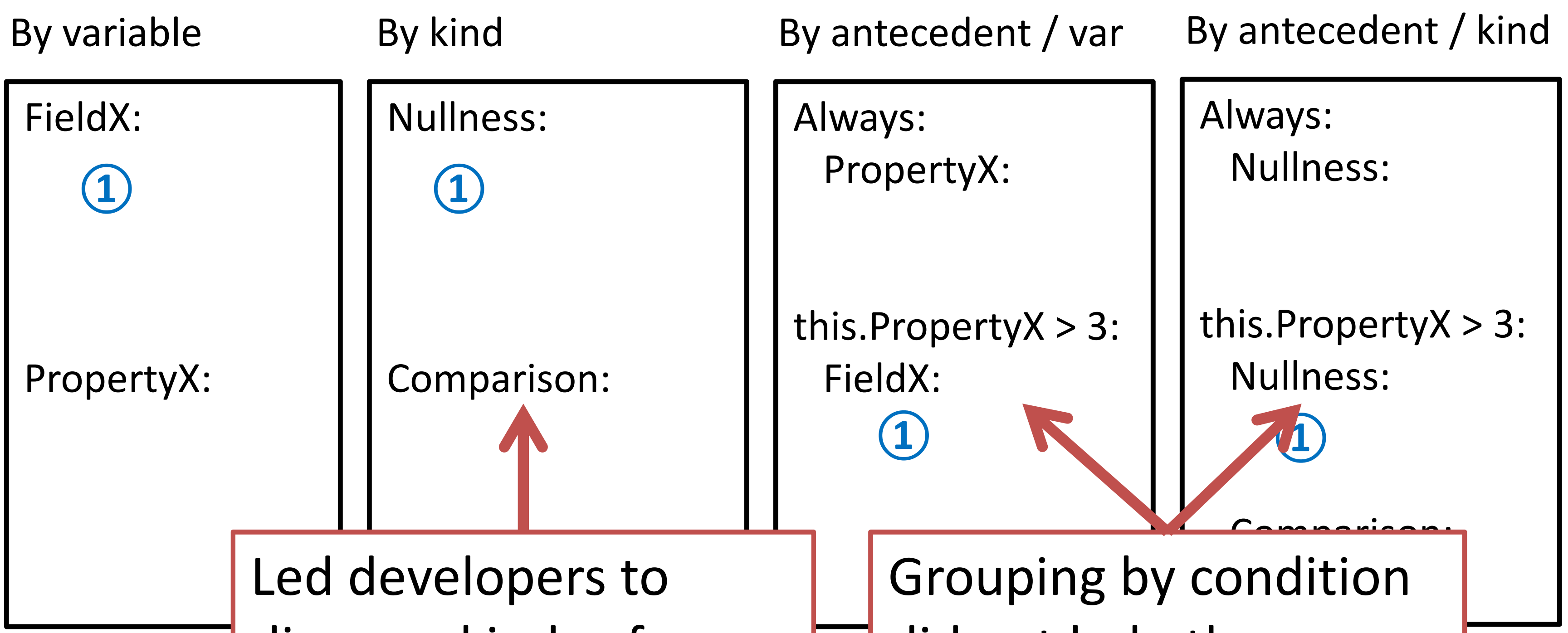


Opportunities to train developers via the tooling itself

- Identifying features that developer is under-utilizing
- Can supplement sound static-checker inference with more expressive inference

UI Grouping Schemes to Encourage Functional Specifications

① (this.PropertyX > 3) implies (this.FieldX != null)



Led developers to discover kinds of contracts they had not considered before

Grouping by condition did not help the developers reason about implications

Related Work

- Contracts in the Wild:
  - Chalin06: Eiffel programs have a lower proportion of non-null checks, higher proportion of postconditions
  - Estler14: Eiffel, JML, and C# contracts are stable over time; preconditions are larger than postconditions

- Human Factors:
  - Polikarpova09: Daikon finds contracts that developers missed
  - Johnson13: false positives and inadequate presentation prevent uptake of static analysis tools

Conclusion: Both Tooling *and* Training are Required for Usability

- Most check missing values, e.g. != null
- Miss aspects of program behavior
- Don't (effectively) use powerful features, e.g., object invariants

Introduce tooling to reduce annotation burden

Make suggestions key part of tool ecosystem

Curate best practices. It's OK to be normative

Tools and Data: http://bit.ly/code-contracts

Lifecycle Not Ideal in Practice

Annotations are too heavy especially the Result/Old syntax is horrid.

The visual studio editor extension is buggy [...] Seeing contracts easily from the call site would be a huge factor in convincing less enthusiastic developers about the benefits.

[The static checker is] too slow, complicated and not expressive enough.

Increased build time is a big problem!

I am not yet totally convinced that [Code Contracts] are ready for prime-time

Subject Projects

Subject Program	**Domain**	**Code Contract Use**	**Other Quality Tools Used**
Labs Framework (11K SLOC)	API exploration framework	Static checking	StyleCop
Mishra Reader (19K SLOC)	RSS reader	Debugging concurrent code	Jetbrains R#
Sando (24K SLOC)	Code search	Early runtime error detection	
Quick Graph (32K SLOC)	Algorithms and data structures	Pex / Testing	Pex

Contract Inserter Interface

Four possible actions:

- Add as contract
- Add as documentation
- Mark as false
- Ignore as implementation detail

Null-checks Can be Expressive

```
public ComplicatedType Foo(. . .){
   Contract.Ensures(Contract.Result<ComplicatedType>() != null);
   . . .
}
```

Types + Contracts Guarantee:

- **Methods Signatures + Method Contracts**
- **Object Invariants**

Tool Information

Celeriac: Contract Inference via Runtime Tracing

https://code.google.com/p/daikon-dot-net-front-end

Contract Inserter: Visual Studio Add-in

https://bitbucket.org/fmc3/scout

Type-State Example: Degenerate Behavior Encoding

```
public class Subscription{
   public SubscriptionsList SubscriptionsList { get; private set; }

   public void AddItem(Item item) {
      Contract.Requires(SubscriptionsList != null, "Call Initialize first");
      . . .
   }

   [InvariantMethod]
   public void ObjectInvariant(){
      . . .
   }
}
```

All contracts use != null

Can’t write an invariant

Type-State Example: Application-Specific Property Encoding

```
public class Subscription {
   public SubscriptionsList SubscriptionsList { get; private set; }
   public boolean IsInitialized { get; private set; }

   public void AddItem(Item item) {
      Contract.Requires(IsInitialized, "Call Initialize first");
      . . .
   }

   [InvariantMethod]
   public void ObjectInvariant(){
      Contract.Invariant(!IsInitialized || SubscriptionsList != null);
      . . .
   }
}
```

Implications can be tricky for multiple states

Mishra Reader: Concurrent Debugging via Nullness Checks

Model subcomponent (of MVC architecture) contained just 11 contracts across 80 classes and 360 methods:

- 10 argument non-null preconditions
- 1 invariant: UnreadCount >= 0

Pattern Example: Encoding Type-State with Contracts

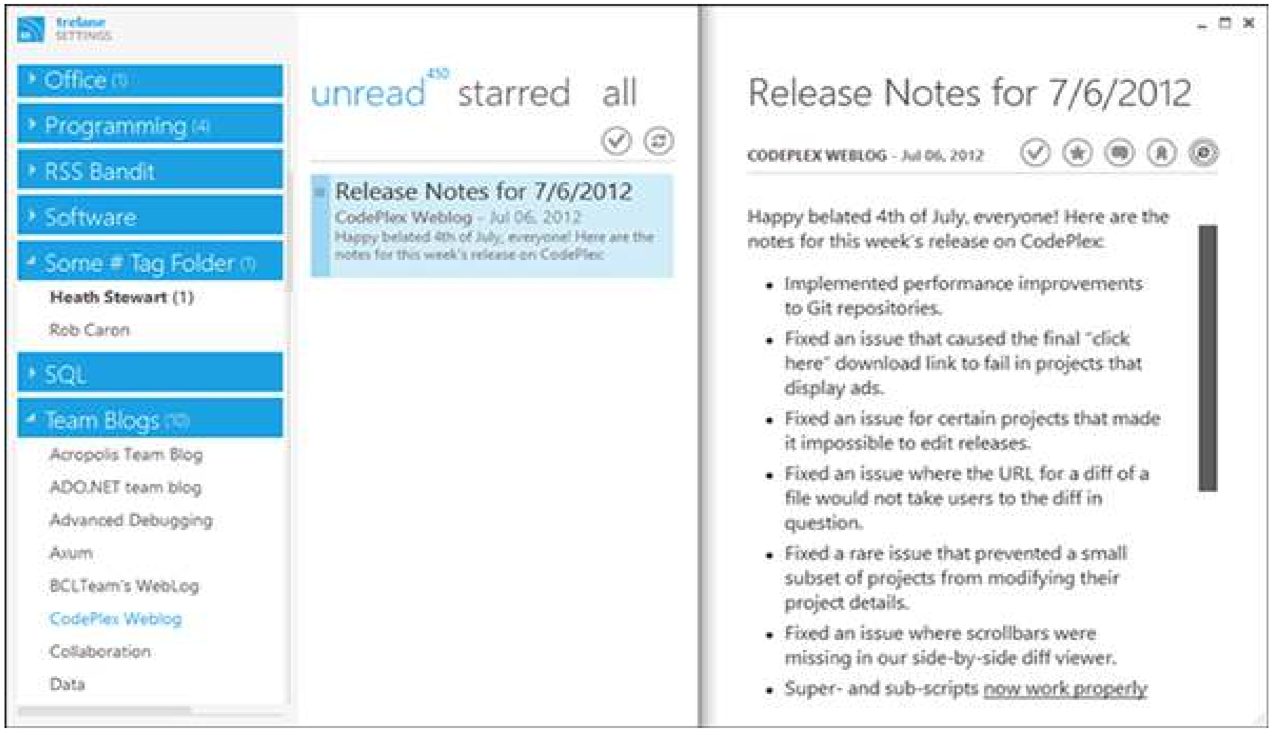
Basic Idea:

- Expose Properties indicating state, e.g., IsOpen
- Contracts contain implications based on state
- Postconditions encode transitions

Observation: only see this pattern in projects that use the static checker

Case Study: Mishra News Reader

Lead developer introduced Contracts to help debug concurrent code



Release Notes for 7/6/2012
CodePlex Weblog - Jul 06, 2012
Happy belated 4th of July, everyone! Here are the notes for this week's release on CodePlex.

Release Notes for 7/6/2012

CODEPLEX WEBLOG - Jul 06, 2012

Happy belated 4th of July, everyone! Here are the notes for this week's release on CodePlex.

- Implemented performance improvements to Git repositories.
- Fixed an issue that caused the final "click here" download link to fail in projects that display ads.
- Fixed an issue for certain projects that made it impossible to edit releases.
- Fixed an issue where the URL for a diff of a file would not take users to the diff in question.
- Fixed a rare issue that prevented a small subset of projects from modifying their project details.
- Fixed an issue where scrollbars were missing in our side-by-side diff viewer.
- Super- and sub-scripts now work properly

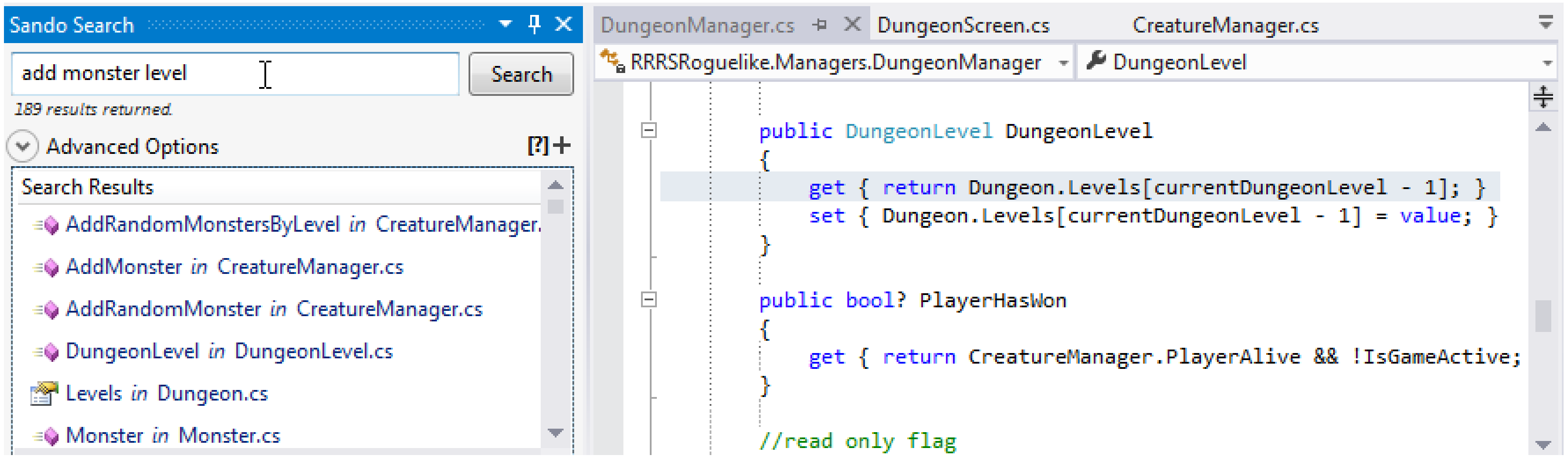
Mishra Reader: Concurrent Debugging via Nullness Checks

Model subcomponent (of MVC architecture) contained just 11 contracts across 80 classes and 360 methods:

- 10 argument non-null preconditions
- 1 invariant: UnreadCount >= 0

Case Study: Sando

Introduced Code Contracts after major contributor saw a webinar



AddRandomMonstersByLevel *in* CreatureManager.
AddMonster *in* CreatureManager.cs
AddRandomMonster *in* CreatureManager.cs
DungeonLevel *in* DungeonLevel.cs
Levels *in* Dungeon.cs
Monster *in* Monster.cs

```
public DungeonLevel DungeonLevel
{
    get { return Dungeon.Levels[currentDungeonLevel - 1]; }
    set { Dungeon.Levels[currentDungeonLevel - 1] = value; }
}

public bool? PlayerHasWon
{
    get { return CreatureManager.PlayerAlive && !IsGameActive;
}

//read only flag
```

Sando: Used Contracts like Assertions

Indexer component contained 17 contracts across 34 classes and 182 methods:

- 12 non-null checks
- 4 non-empty checks
- 1 implication:

```
!criteria.SearchByUsageType || criteria.UsageTypes.Count > 0
```