# Program Analysis 2.0

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# Program Analysis 1.0 (1999-200?)

1. Legacy focus
2. The static analysis genie
3. Scale via aggressive abstraction
4. The genie out of the bottle → false alarms

# Program Analysis 2.0

1. Constraints are empowering
2. Diversification → growth
3. Scale by decomposition
4. Rebottle the genie!

# Some Program Analysis 2.0 Tools

- **Code contracts for .NET**
  - MSIL rewriting, dynamic + static checking
- **Automatic test data generation (Pex)**
  - Symbolic execution with SMT solvers (Z3)
- **Systematic concurrency testing (CHESS)**
  - Direct model checking of code

# Available for Academic/Commercial Use

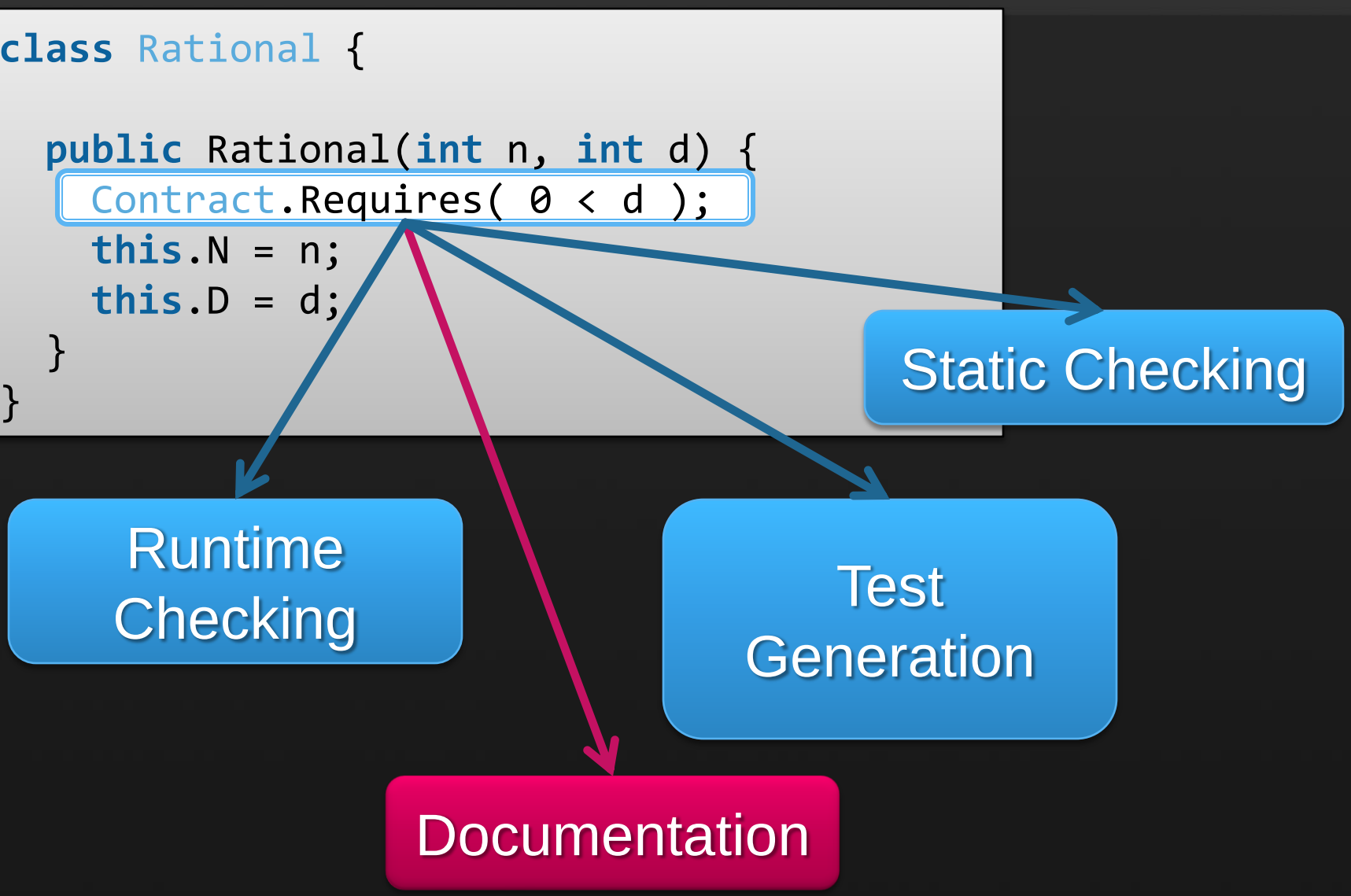
- Academic
  - http://research.microsoft.com/contracts/
  - http://research.microsoft.com/pex/
  - http://research.microsoft.com/chess/
- Commercial
  - http://msdn.com/devlabs/

# Code Contracts for .NET 4.0

- Mike Barnett
- Manuel Fähndrich
- Francesco Logozzo

# Code Contracts for .NET 4.0

```
class Rational {

  public Rational(int n, int d) {
    Contract.Requires( 0 < d );
    this.N = n;
    this.D = d;
  }
}
```



# What Contracts Can I Write?

- Requires
  - What must be true at method entry
- Ensures
  - What must be true at method exit
- Invariants
  - What must be true at all method exits
- Assertions
  - What must be true at a particular point
- Assumptions
  - What should be true at a particular point

# What Can I Put In A Contract?

- Any Boolean expression
  - In your favorite programming language!
  - Including method calls (but must be marked Pure)
- Quantifiers
  - Contract.ForAll(0,A.Length,i => A[i] > 0);
  - Contract.Exists(0,A.Length,i => A[i] > 0);
- Contract.Result
  - refer to the return value of the method
- Contract.OldValue
  - refer to values at method entry

# How Do I Write A Contract?

```
public virtual int Add(object value)
{

  Contract.Requires( value != null );
  Contract.Ensures( Count == Contract.OldValue(Count) + 1 );
  Contract.Ensures( Contract.Result<int>() == Contract.OldValue(Count) );

  if (count == items.Length) EnsureCapacity(count + 1);
  items[count] = value;
  return count++;
}
```

```
void ObjectInvariant() {
  Contract.Invariant( items != null );
}
```

**Features**

- Declarative
- Language expression syntax
  - Type checking / IDE
- Special Encodings
  - Result and OldValue

# How Does It Work?

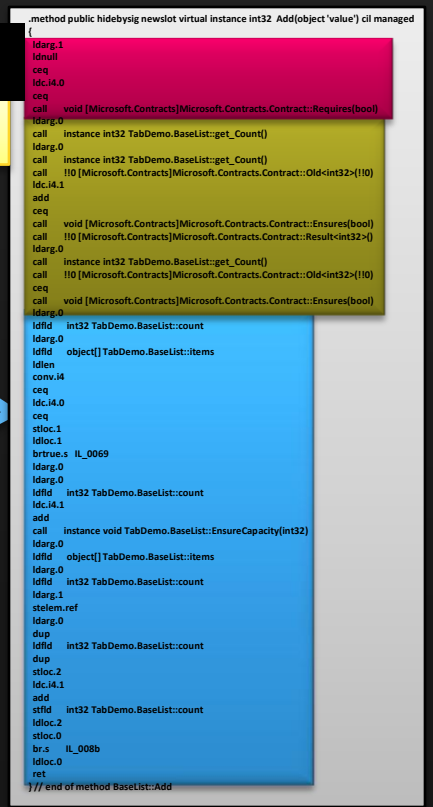
```
public virtual int Add(object value){
    Contract.Requires( value != null );

    Contract.Ensures( Count == Contract.OldValue(Count) + 1 );
    Contract.Ensures( Contract.Result<int>() == Contract.OldValue(Count) );

    if (_size == _items.Length) EnsureCapacity(_size+1);
    _items[_size] = value;
    return _size++;
}
```

csc/vbc/...

Release Compile

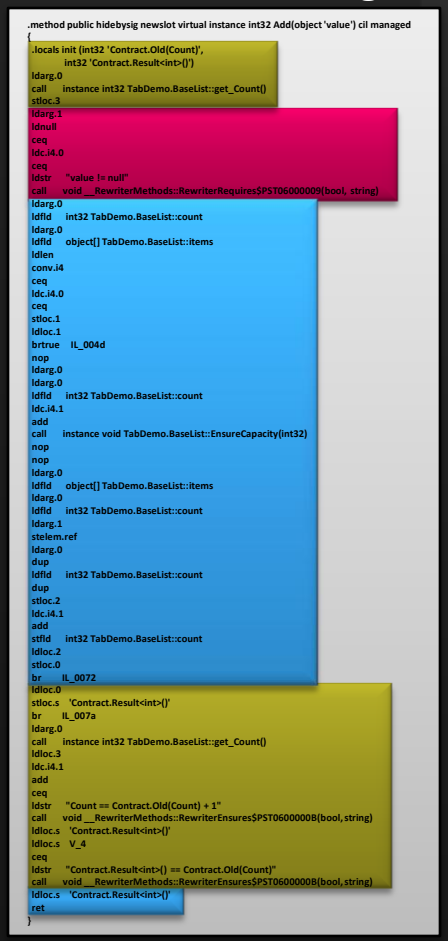

/d:CONTRACTS_FULL

csc/vbc/...

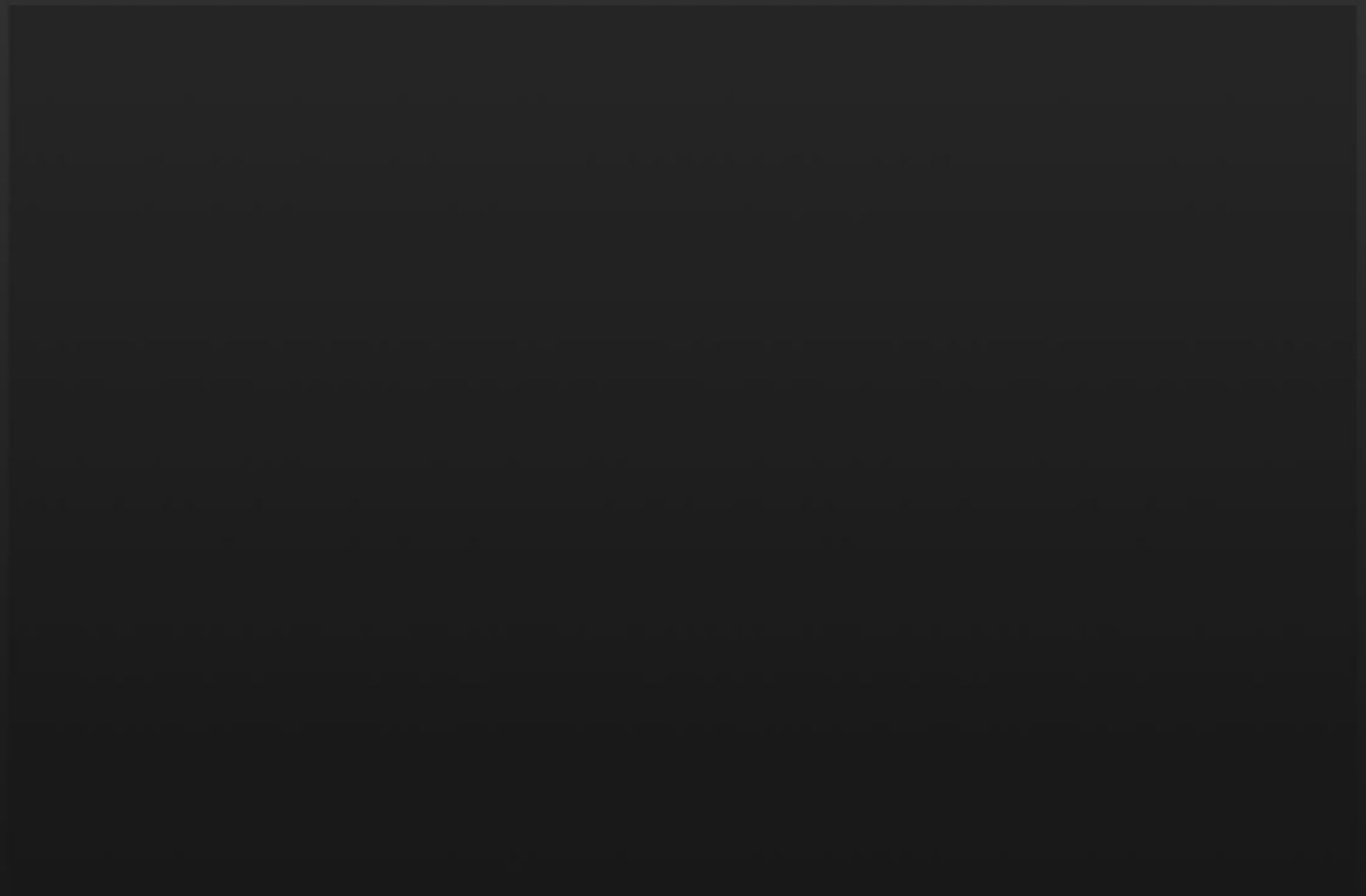



ccrewrite

Executable Runtime Contract Checking



# Demo of Heap example



# Code Contracts Summary

- Enables contracts in all .NET languages
  - No restrictions on what can be expressed
- Contract library a core component of .NET 4.0
- Same contracts used for
  - Runtime checking
  - Static checking
  - Documentation generation

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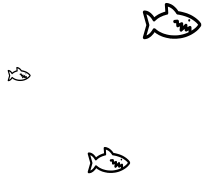
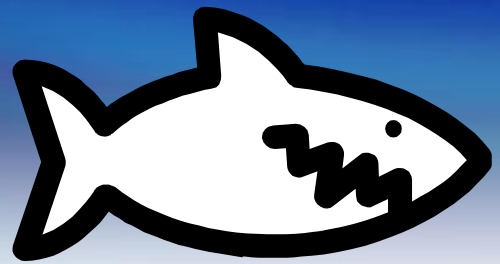
# White Box Test Generation for .NET

Nikolai Tillmann, Peli de Halleux
Microsoft Research



# Pex: Overview



- Purpose: Test input generator
  - Start from unmodified code (or code with contracts)
  - Generated tests emitted as traditional unit tests
  - Goal: test suite that covers all reachable statements
- Technology: Dynamic symbolic execution
  - Whole-program, white-box code analysis
  - At the level of the .NET instructions (bytecode)
  - Symbolic execution based on monitoring and re-execution
  - Constraint solver (Z3) determines test inputs for new paths

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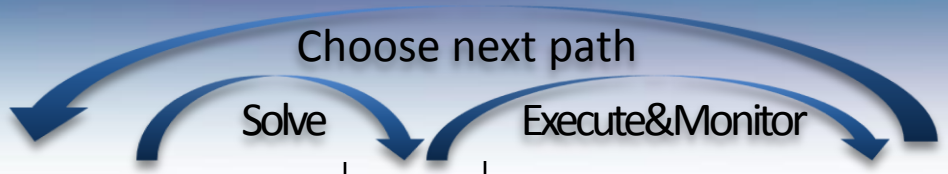
# Dynamic Symbolic Execution By Example

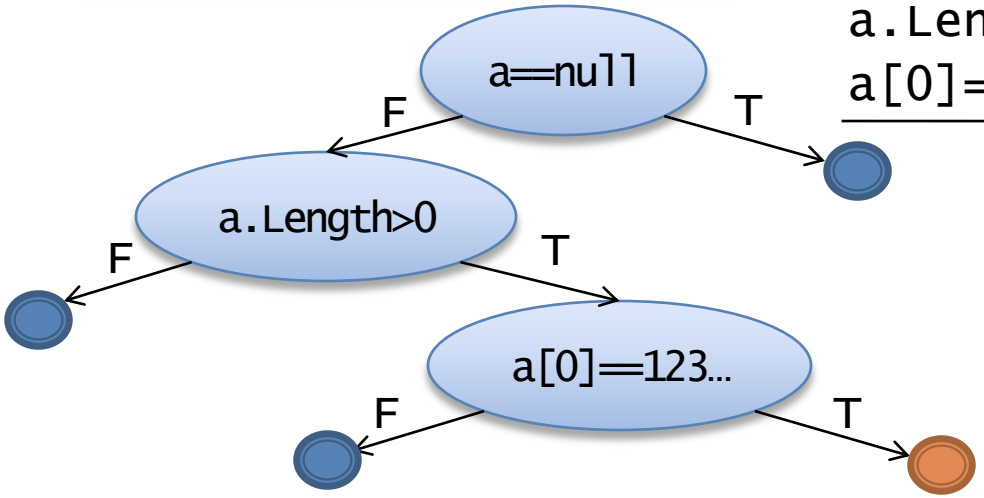



**Code to generate inputs for:**

```
void CoverMe(int[] a)
{
  if (a == null) return;
  if (a.Length > 0)
    if (a[0] == 1234567890)
      throw new Exception("bug");
}
```

| Constraints to solve | Input | Observed constraints |
|---|---|---|
| | null | a==null |
| a!=null | {} | a!=null && |
| a!=null<br>a.Length>0 | | a.Length>0 &&<br>a[0]!=1234567890 |
| a!=null &&<br>a.Length>0 &&<br>a[0]==1234567890 | {123...} | a==null &&<br>a.Length>0 &&<br>a[0]==1234567890 |

Negated condition




**Done: There is no path left.**

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# Into the Real World

## How to test this code?

(Actual code from .NET base class libraries.)

```
[SecurityPermissionAttribute(SecurityAction.LinkDemand, Flags=SecurityPermissionFlag.SerializationFormatter)]
public ResourceReader(Stream stream)
{
    if (stream==null)
        throw new ArgumentNullException("stream");
    if (!stream.CanRead)
        throw new ArgumentException(Environment.GetResourceString("Argument_StreamNotReadable"));

    _resCache = new Dictionary<String, ResourceLocator>(FastResourceComparer.Default);
    _store = new BinaryReader(stream, Encoding.UTF8);
    // We have a faster code path for reading resource files from an assembly.
    _ums = stream as UnmanagedMemoryStream;

    BCLDebug.Log("RESMGRFILEFORMAT", "ResourceReader .ctor(Stream).  UnmanagedMemoryStream: "+(_ums!=null));
    ReadResources();
}
```

# Real World (II)

```
        // Reads in the header information for a .resources file.  Verifies some
        // of the assumptions about this resource set, and builds the class table
        // for the default resource file format.
        private void ReadResources() {
            BCLDebug.Assert(_store != null, "ResourceReader is closed!");
            BinaryFormatter bf = new BinaryFormatter(null, new StreamingContext(StreamingContextStates.File |
#if !FEATURE_PAL
            _typeLimitingBinder = new TypeLimitingDeserializationBinder();
            bf.Binder = _typeLimitingBinder;
#endif
            _objFormatter = bf;
            try {
                // Read ResourceManager header
                // Check for magic number
                int magicNum = _store.ReadInt32();
                if
                //
                //
                //
                int
                if
                } e
                // Read in type name for a suitable ResourceReader
                // Note BinaryWriter & InternalResGen use different Strings
```

```
public virtual int ReadInt32() {
    if (m_isMemoryStream) {
        // read directly from MemoryStream buffer
        MemoryStream mStream = m_stream as MemoryStream;
        BCLDebug.Assert(mStream != null, "m_stream as MemoryStream != null");

        return mStream.InternalReadInt32();
    }
    else
    {
        FillBuffer(4);
        return (int)(m_buffer[0] | m_buffer[1] << 8 | m_buffer[2] << 16 | m_buffer[3] << 24);
    }
}
```

# Demos

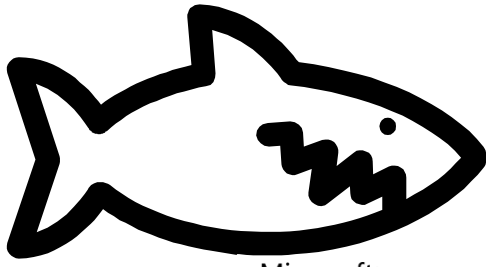
## - test generation of Heap with contracts-

## - test the ResourceReader-

# Summary

- *Pex* automates test input generation for .NET programs
- *Pex* enables Parameterized Unit Testing
- Used in Microsoft to test core .NET components

- http://research.microsoft.com/pex



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# Concurrency Analysis Platform And Tools For Finding Concurrency Bugs


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→ Shaz Qadeer
Senior Researcher
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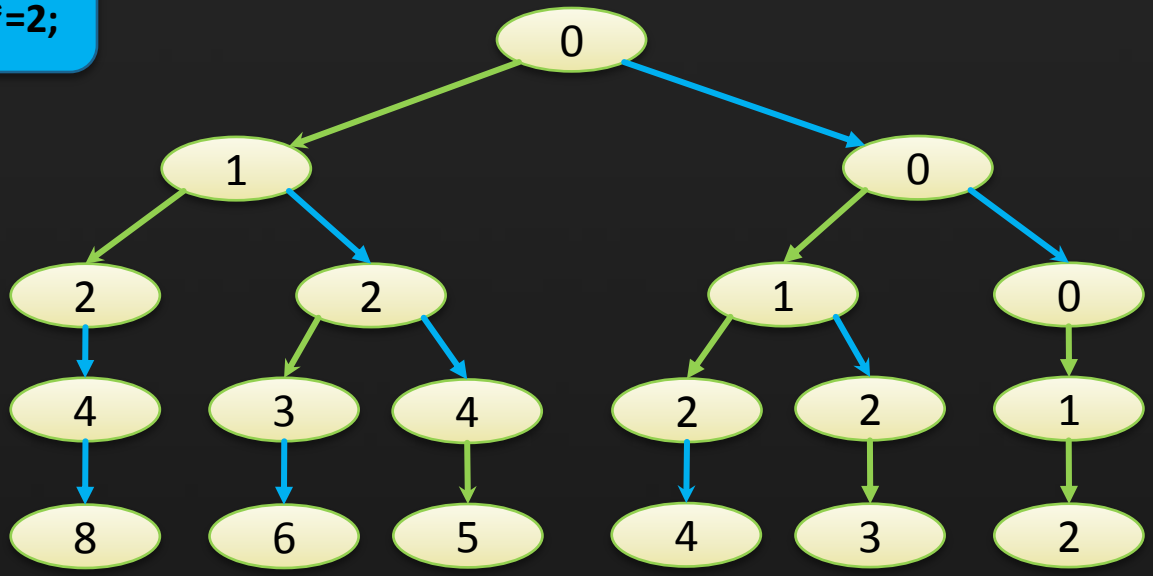
# Thread Interleavings

Thread 1

```
x++;
x++;
```

Thread 2

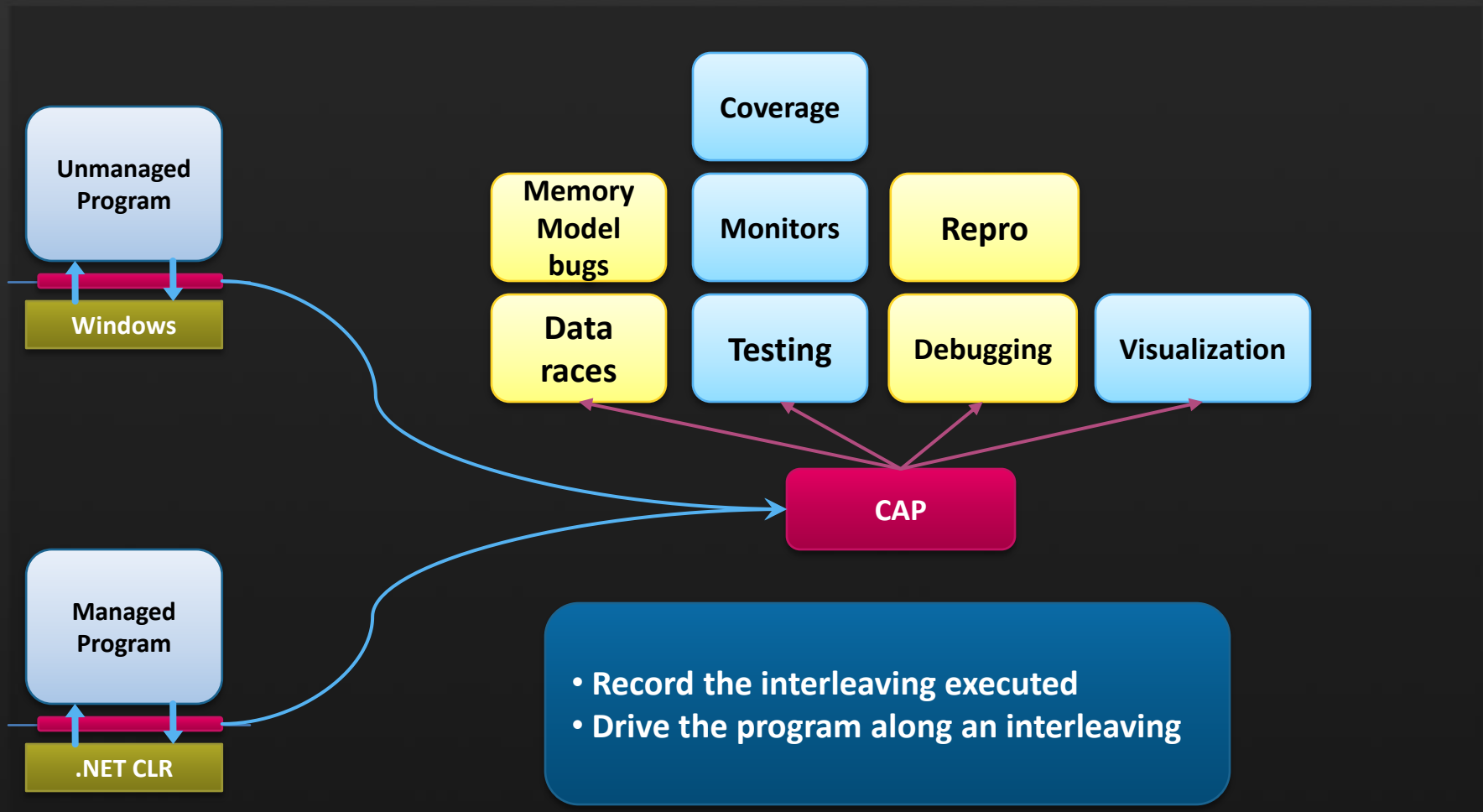
```
x*=2;
x*=2;
```



# Concurrency Analysis Platform (CAP)

- **Goal**: Drive a program along an interleaving of choice
  - Interleaving decided by user or by a program/tool
- **Today**: Controlling/observing concurrency is difficult
  - Manual and intrusive process
- Enables lots of concurrency tools:
  - Test a program along a set of interleavings
  - Reproduce Heisenbugs
  - Program understanding / debugging
  - ...

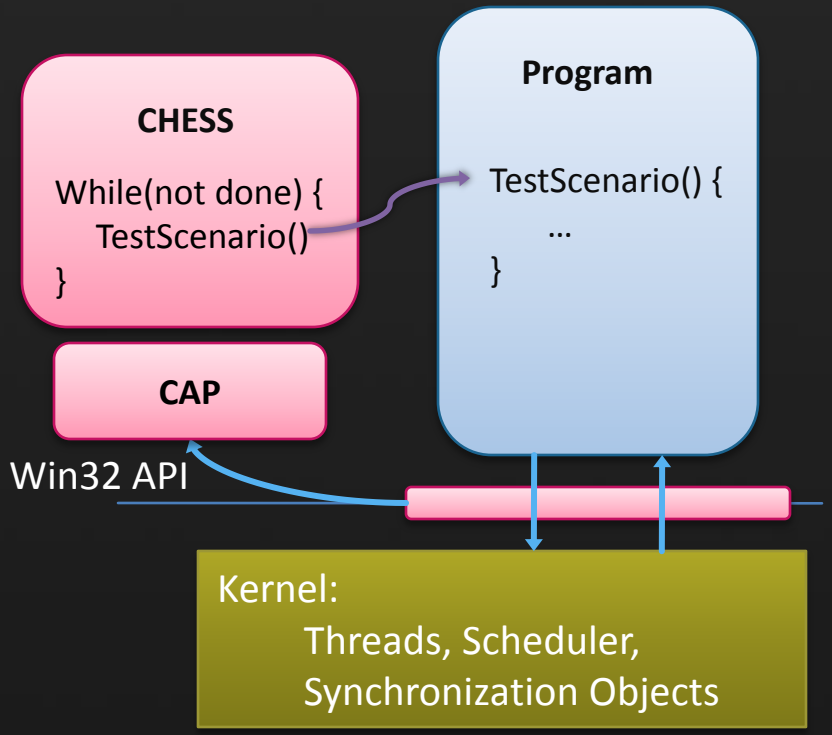
# CAP Architecture



# CAP Specifics

- Ability to explore all interleavings
  - Need to understand complex concurrency APIs (Win32 and System.Threading)
  - Threads, threadpools, locks, semaphores, async I/O, APCs, timers, …
- Does not introduce false behaviors
  - Any interleaving produced by CAP is possible on the real scheduler

# CHESS: Find And Reproduce Heisenbugs




CHESS runs the scenario in a loop

- Every run takes a different interleaving
- Every run is repeatable

Uses the CAP scheduler

- To control and direct interleavings

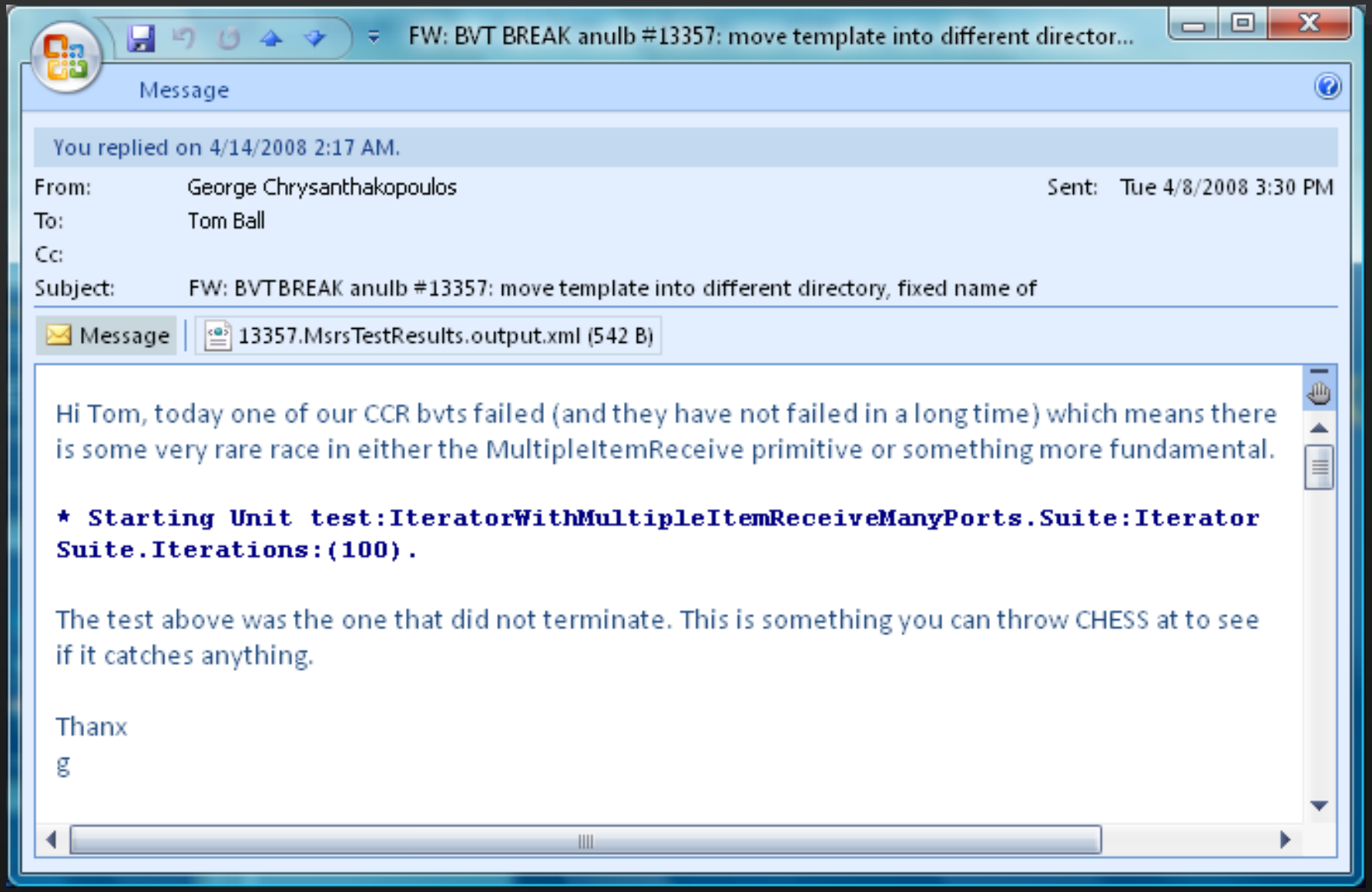
Detect

- Assertion violations
- Deadlocks
- Dataraces
- Livelocks

# CHESS Internal Customers

- Parallel Computing Platform
  - PLINQ:  Parallel LINQ
  - CDS:  Concurrent Data Structures
  - STM:  Software Transactional Memory
  - TPL:  Task Parallel Library
  - ConcRT:  Concurrency RunTime
  - CCR:  Concurrency Coordination Runtime
- Dryad/Cosmos
- Singularity (Research OS from MSR)
  - CHESS can systematically test the boot and shutdown process

# George Chrysanthakopoulos' Challenge



# Program Analysis 2.0

1. Constraints are empowering
2. Diversification → growth
3. Scale by decomposition
4. Rebottle the genie!