CHESS or “How to track Heisenbugs”

Presentation of:

Finding and reproducing Heisenbugs in concurrent programs

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By: Mathias Dürrenberger

What is a Heisenbug ?

- Werner Karl Heisenberg (5 Dec 1901 - 1 Feb 1976)
- Uncertainty principle
- The bug disappears when we try to debug the code

What is a Heisenbug ?

- The bug only appears when compiler optimizations are enabled
- Multithreaded systems: occasional/rare race conditions - thread scheduling is essentially non-deteministic

➨Big productivity issue (it can take weeks to find one)

➨And often huge associated risks too

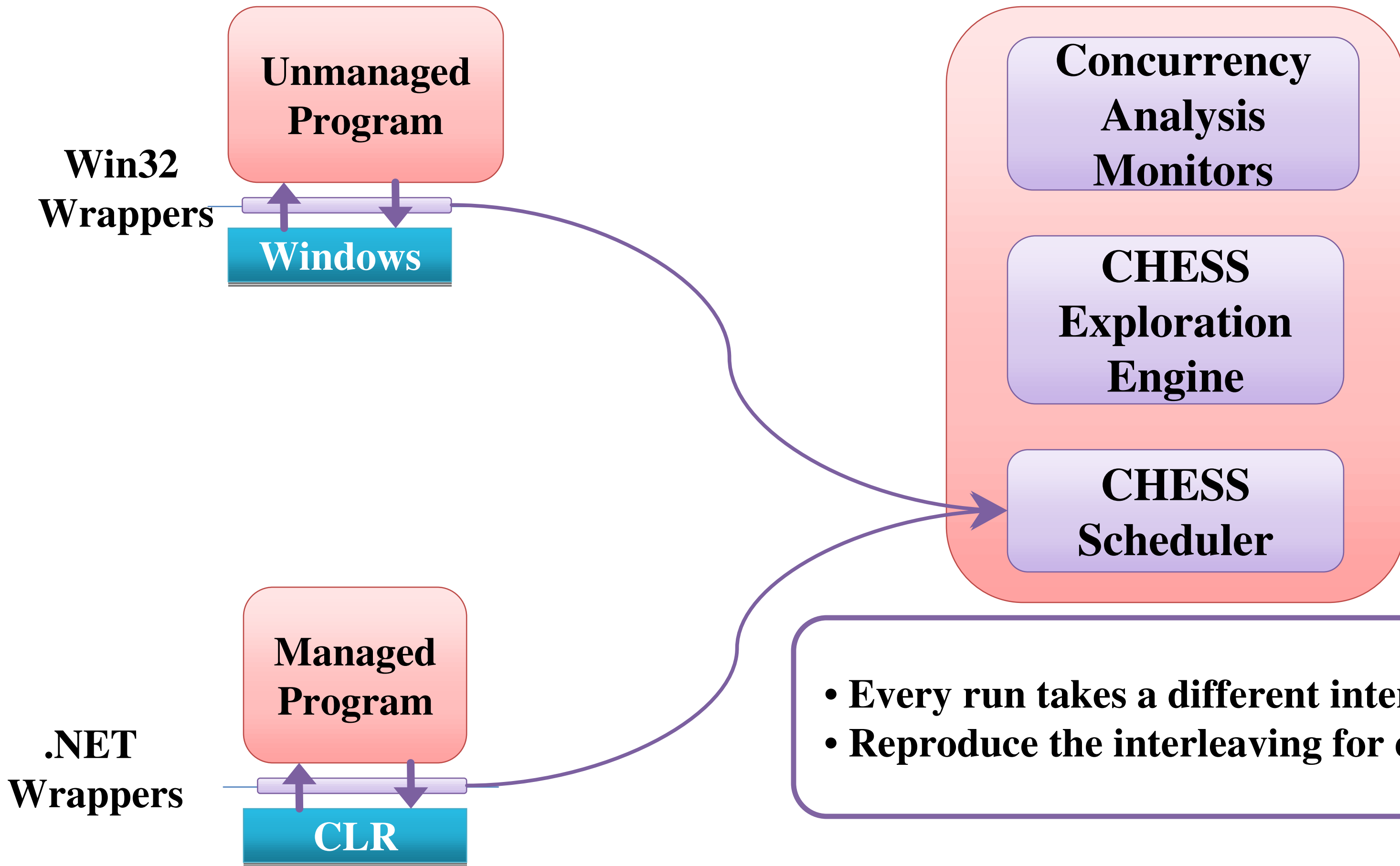
Why Heisebugs matter

- Failure of real time systems can have catastrophic consequences !
  - Nuclear power plant
  - Engine control systems
  - Driving assistance (break control, traction control, ...)
  - Locomotive control systems
  - etc

How does CHESS work ?

- Take full control of scheduling of threads and of asynchronous events
- Capture interleaving nondeterminism of program with a Lamport happens-before graph
- Reduce state space
- Drives program through possible thread interleavings

CHESS Architecture



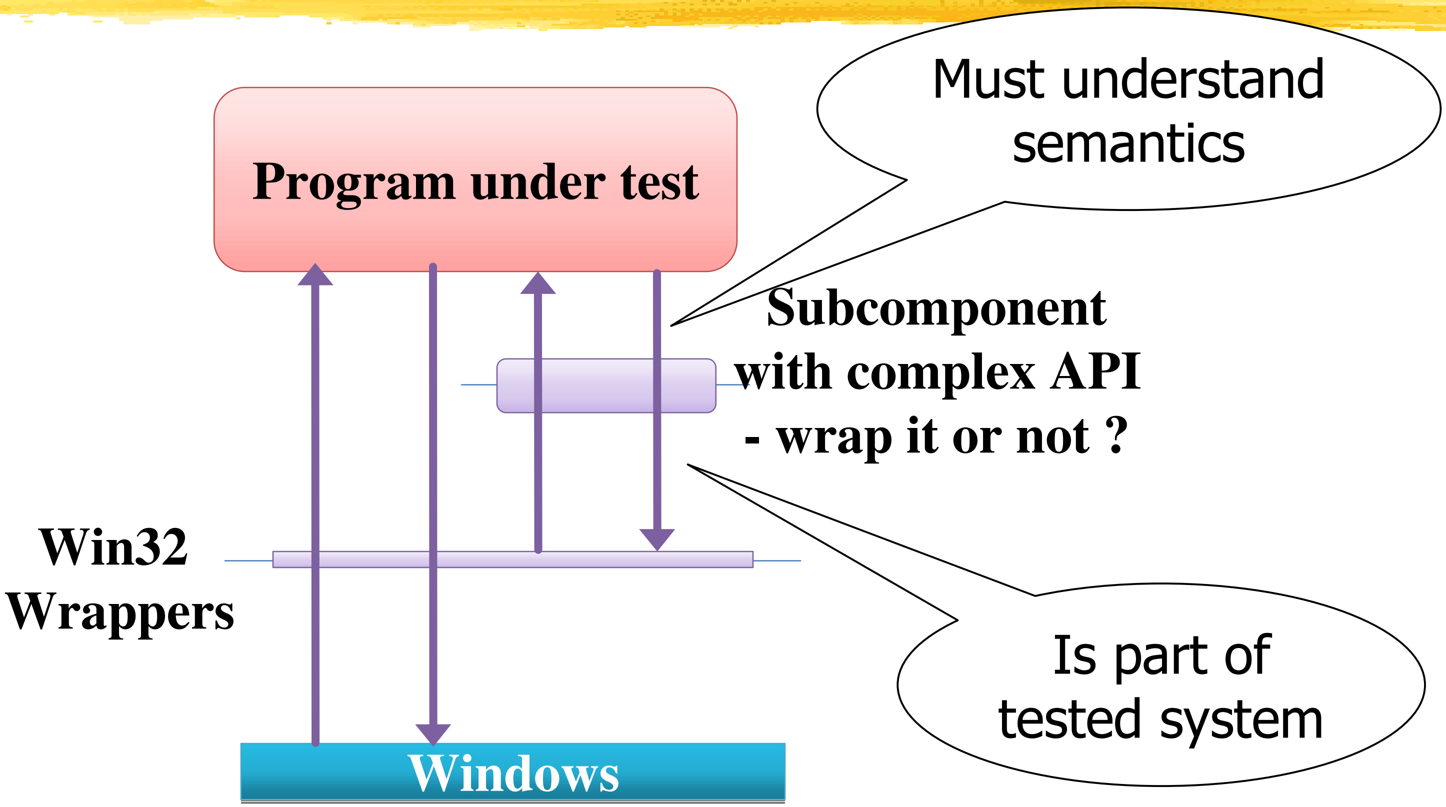
- Every run takes a different interleaving
- Reproduce the interleaving for every run

Source: Microsoft

How CHESS interacts

- Win32: DLL-shimming (overwriting the import address table of the program under test)
- .Net: extended CLR profiler
- Singularity: static IL rewriter
- Consider sub-components with complex API as part of application under test

Wrappers



Must understand semantics
Program under test
Subcomponent with complex API - wrap it or not ?
Win32 Wrappers
Is part of tested system
Windows

Main idea: replace the scheduler

Basic functions of CHESS scheduler: playback and monitor

- Playback from trace file
- Launch a thread
- Record events during time slice of a thread into trace file

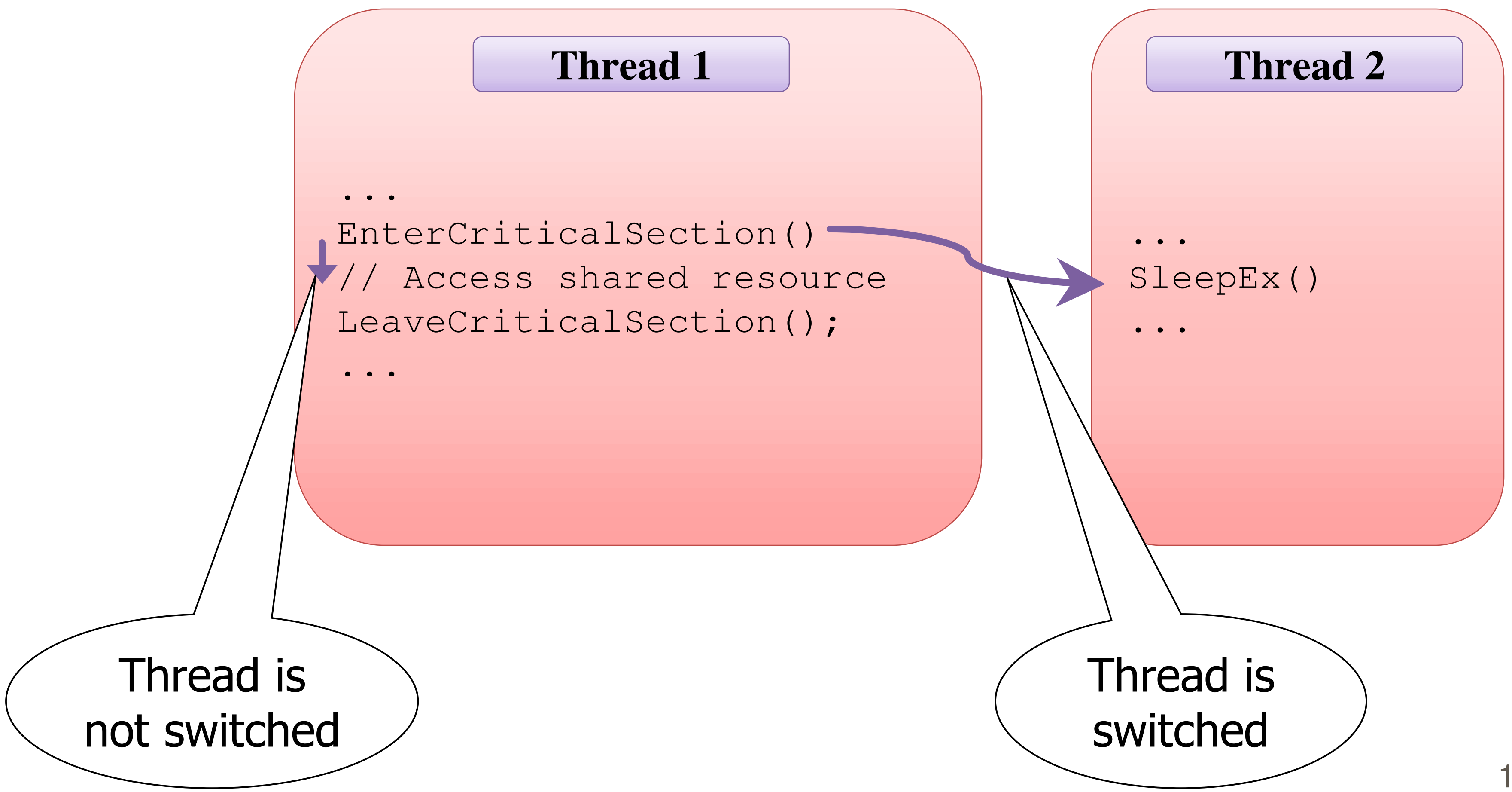
One step further: generate a new thread interleaving

- Use the recorded information to find an interesting next schedule in a smart way (called: search)
- This is an iterative process

Record

- Disturb system under test as little as possible
- We do not want to change the real time behavior in a significant way
- Must understand the semantics of concurrent API's
- Monitor concurrency primitives: **`EnterCriticalSection`**, **`ReleaseCriticalSection`**, **`CreateThread`**, **`QueueUserWorkItem`**, **`CreateTimerQueueTimer`**, **`asynchronous file I/O, ...`**

Example


Thread 1
...
EnterCriticalSection()
// Access shared resource
LeaveCriticalSection();
...
Thread 2
...
SleepEx()
...
Thread is not switched
Thread is switched

Control flow model

- Current executing task
- Map of resource handles to synchronization variables
- Set of enabled tasks
- Set of threads waiting on each synchronization variable
- ➨ Determine if call switches thread
- ➨ Determine if call yields new task/terminates task

Does CHESS deliver ?

- Failure of a nightly test run (after many month's of successes)
  - ➡ Isolate offending unit (comment out the rest in test harness) => 30 minutes
  - ➡ Running under CHESS => 20 seconds to discover a deadlock
  - ➡ Run code in standard debugger, with the offending schedule being driven by CHESS
- Several other projects where CHESS has been used successfully within Microsoft

Concluding remarks

- The direction is right, it’s a promising approach
- But does it target the platform that matters ?
- Win32 has a bad reputation as real time platform (I.e. interrupt latency)
- What about Linux and other industrial real time OS’s ?
- Porting is rather complex (Win32: 134 lib’s with 2512 functions, .net: 64 lib’s with 1270 functions)

Example: `EnterCriticalSection`

- Can block (switch the thread) or immediately acquire the resource
  - Emulate call with combination of: `TryEnterCriticalSection` and `EnterCriticalSection`
- Record outcome in "operation" value
- Update control flow model
  - If "try" fails, add current task to set of taks waiting on that resource, remove from set of enabled tasks
  - When released, move all tasks from waiting set to enabled set

Model of concurrent interactions

- Lamport: happens-before graph, use to model relative execution order of threads
- Node := (task, synchronization variable, operation)
- Task :- { thread, threadpool work item, asynchronous callback, timer callback }
- Synchronization variable :- { lock, semaphores, atomic variables accessed, queues }
- Operation :- [isWrite (changes state of resource), isRelease (unlocks tasks waiting on that resource)]

Summary: graph node

- Task: take current executing task
- Synchronization variable: get from resource handle map
- Operation: get from call semantics/analysis
- Advantage: is robust by design and fault tolerant

And the edges ?

- They are built, based on analysis of inter-thread communication
- Operation: isWrite, isRelease (from contents of node)
- Can this call disable the current task ? I.e. result in a thread switch ?
- Requires to model the control flow among threads
- Understanding of call semantics needed

CHESS scheduler

- Iterate on: **replay**, **record**, **search**
- **replay**: redo a previous path
- **record**: behave as fair, nonpreemptive scheduler, let thread run until it yields control, process graph
- **search**: systematically enumerate possible thread interleavings, come up with an interesting schedule

➨ Problem: how to reduce state space ?

Reduce state space

- Bound number of preemptions: three is enough to find almost any bug
- Scope preemptions: exclude standard libraries (I.e. C run time)
- Only use preemption at very specific places (when accessing shared variables)

Further readings

Additional materials:

http://research.microsoft.com/en-us/projects/chess/

Can be downloaded for MS Visual Studio 2008

References

- LAMPORT, L. Time, clocks, and the ordering of events in a distributed system. *Communications of the ACM 21*, 7 (1978), 558–565.
- LU, S., PARK, S., SEO, E., AND ZHOU, Y. Learning from mistakes: a comprehensive study on real world concurrency bug characteristics. In *ASPLOS 08: Architectural Support for Programming Languages and Operating Systems* (2008).
- MUSUVATHI, M., AND QADEER, S. Iterative context bounding for systematic testing of multithreaded programs. In *PLDI07: Programming Language Design and Implementation* (2007), pp. 446–455.