



INTERMITTENT MULTI-THREADING BUGS: FIND AND SQUASH RACES, DEADLOCKS, AND MEMORY BUGS

Memory & Thread Debugger

Here is What Will Be Covered

Overview

Memory/Thread analysis

New Features

Deep dive into debugger integrations

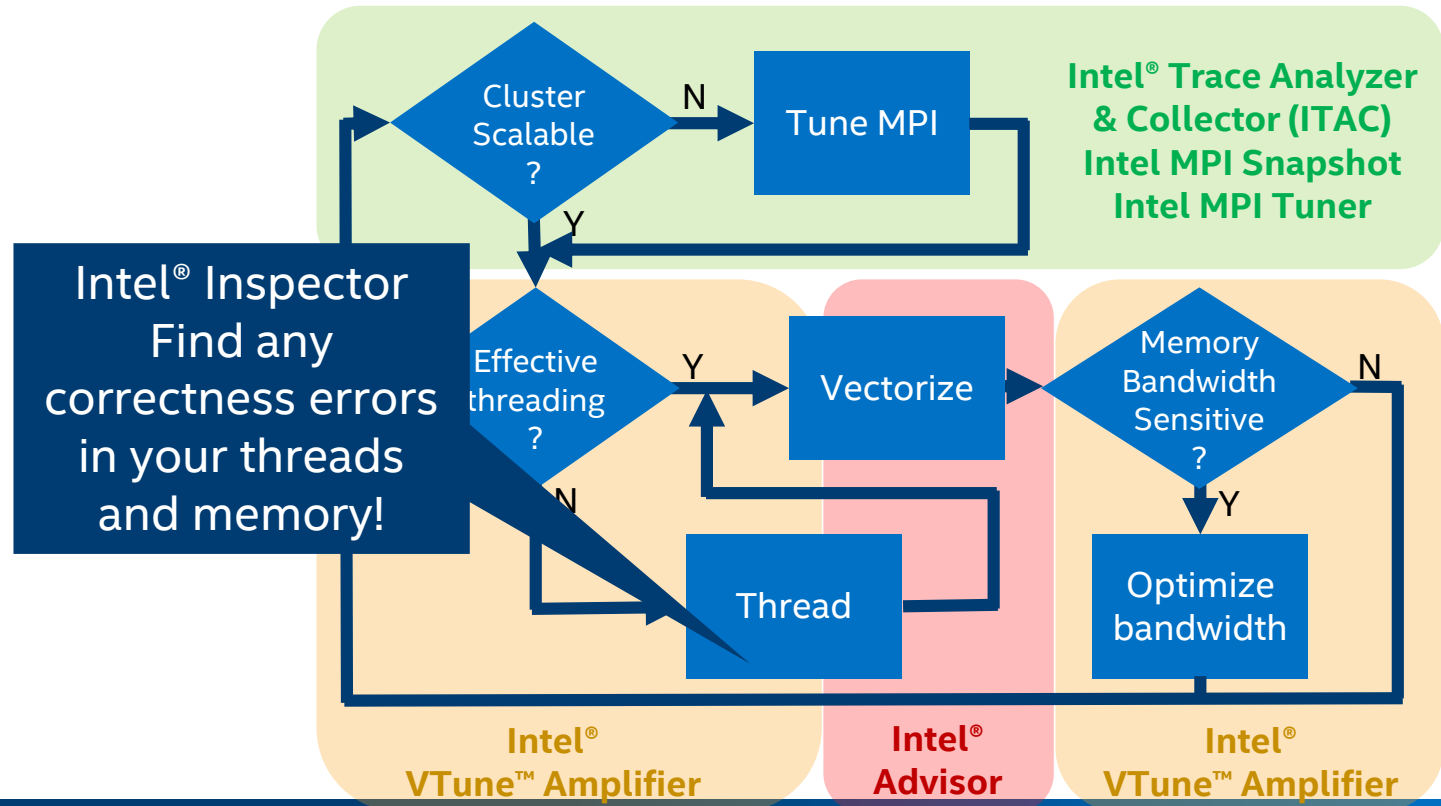
Demo

Call to action

Analysis Tools for Diagnosis

Intel® Parallel Studio XE

Intel® Parallel
Studio XE



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Correctness Tools Increase ROI By 12%-21%

Cost Factors – Square Project Analysis

CERT: U.S. Computer Emergency Readiness Team, and Carnegie Mellon CyLab

NIST: National Institute of Standards & Technology : Square Project Results

Size and complexity of applications is growing



Correctness tools find defects during development prior to shipment

Reworking defects is 40%-50% of total project effort

Reduce time, effort, and cost to repair

Find errors earlier when they are less expensive to fix

Find & Debug Memory & Threading Errors

Intel® Inspector – Memory & Thread Debugger

Correctness Tools Increase ROI By 12%-21%¹

- Errors found earlier are less expensive to fix
- Several studies, ROI% varies, but earlier is cheaper

Diagnosing Some Errors Can Take Months

- Races & deadlocks not easily reproduced
- Memory errors can be hard to find without a tool

Debugger Integration Speeds Diagnosis

- Breakpoint set just before the problem
- Examine variables & threads with the debugger

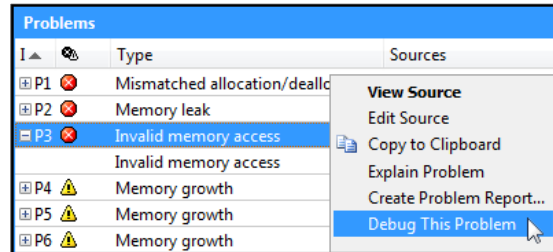
Diagnose in hours instead of months

¹ Cost Factors – Square Project Analysis

CERT: U.S. Computer Emergency Readiness Team, and Carnegie Mellon CyLab

NIST: National Institute of Standards & Technology : Square Project Results

Debugger Breakpoints



Part of Intel® Parallel Studio
For Windows* and Linux*

Intel® Inspector dramatically sped up our ability to track down difficult to isolate threading errors before our packages are released to the field.

*Peter von Kaenel, Director,
Software Development,
Harmonic Inc.*

<http://intel.ly/inspector-xe>

Debug Memory & Threading Errors

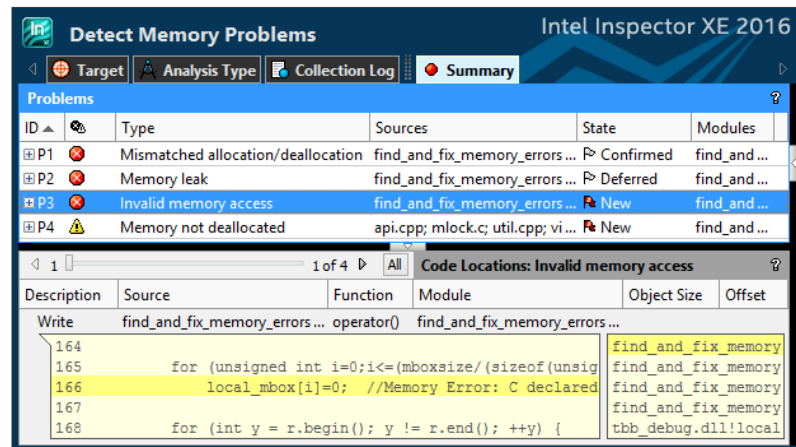
Intel® Inspector

Find and eliminate errors

- Memory leaks, invalid access...
- Races & deadlocks
- C, C++, C#, F# and Fortran (or a mix)

Simple, Reliable, Accurate

- No special recompiles
Use any build, any compiler¹
- Analyzes dynamically generated or linked code
- Inspects 3rd party libraries without source
- Productive user interface + debugger integration
- Command line for automated regression analysis



Clicking an error instantly displays source code snippets and the call stack

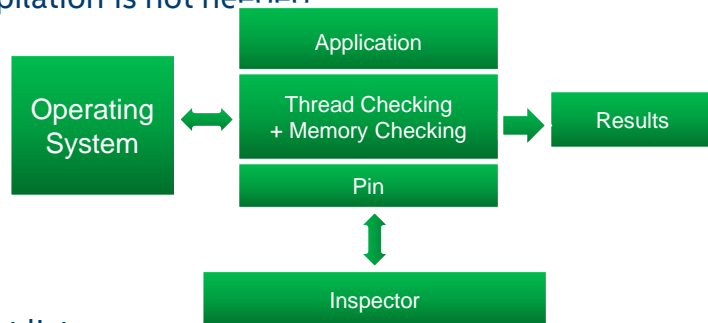
Fits your existing process

Intel® Inspector dynamic analysis

Data Collection Techniques

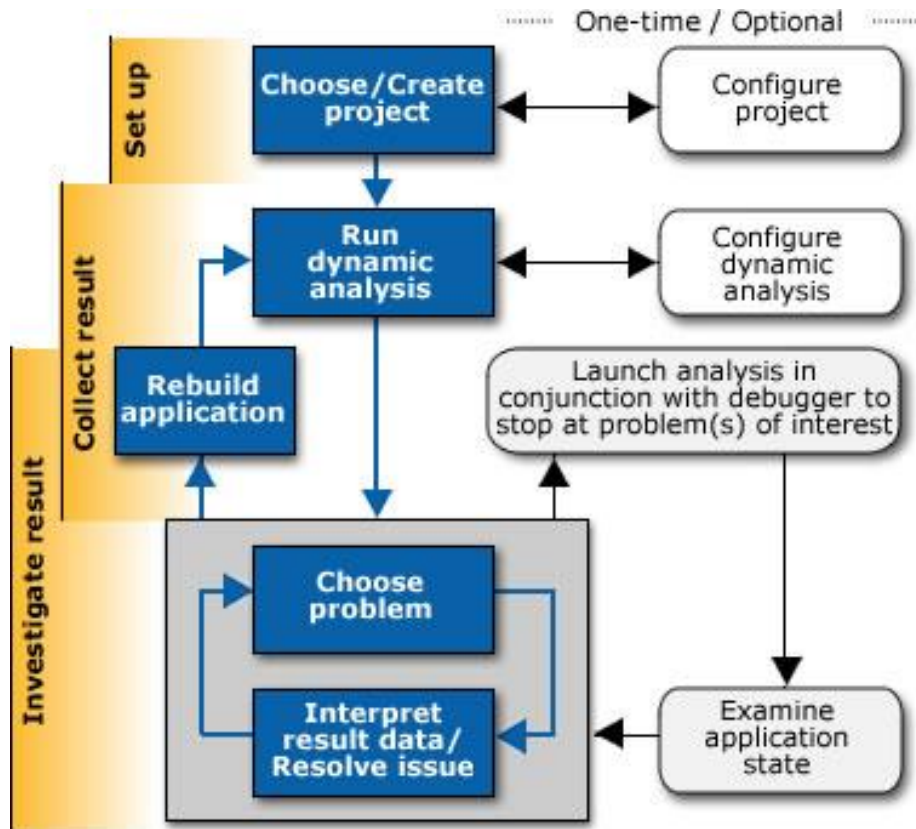
Inspector tracks all memory allocations and threading APIs using a binary instrumentation tool called Pin

- Dynamic instrumentation system provided by Intel (<http://www.pintool.org>)
- Injected code used for observing the behaviour of the program
- Source modification/recompilation is not needed



- OS has to be in the support list
- One process is analysed at a time

Recommended Methodology



Race Conditions Are Difficult to Diagnose

They only occur occasionally and are difficult to reproduce

Correct

Thread 1	Thread 2		Shared Counter
			0
Read count		←	0
Increment			0
Write count		→	1
	Read count	←	1
	Increment		1
	Write count	→	2

Incorrect

Thread 1	Thread 2		Shared Counter
			0
Read count		←	0
	Read count	←	0
Increment			0
	Increment		0
Write count		→	1
	Write count	→	1

Productive User Interface Saves Time

Intel® Inspector

Select a problem set

Code snippets displayed for selected problem

The screenshot displays the Intel Inspector XE 2016 interface. At the top, the title bar reads "Detect Memory Problems" and "Intel Inspector XE 2016". Below the title bar are tabs for "Target", "Analysis Type", "Collection Log", and "Summary". The main window is divided into several sections:

- Problems Table:** A table with columns "Type", "Sources", "State", and "M". It lists several memory-related issues, including "Mismatched allocation/deallocation", "Memory leak", "Invalid memory access", and "Memory not deallocated". The "State" column shows various statuses like "Confirmed", "Deferred", "New", and "tb".
- Filters Panel:** A panel on the right side of the "Problems" table, titled "Filters". It includes sections for "Severity", "Type", and "Source", each with a list of items and counts.
- Code Locations:** A section below the "Problems" table, titled "Code Locations: Mismatched allocation/deallocation". It shows a table with columns "Description", "Source", "Function", "Module", "Object Size", and "Offset".
- Code Snippets:** Two code snippets are displayed below the "Code Locations" table. The first snippet is for a "Mismatched deallocation site" and the second is for an "Allocation site". Both snippets show C++ code with line numbers and comments.

Filters let you focus on a module, or error type, or just the new errors or...

Problem States: New, Not Fixed, Fixed, Confirmed, Deferred, Regression

Double Click for Source & Call Stack

Intel® Inspector

Source code locations displayed for selected problem

The screenshot displays the Intel Inspector XE 2016 interface. The main window title is "Mismatched allocation/deallocation". The top toolbar includes buttons for "Target", "Analysis Type", "Collection Log", "Summary", and "Sources". The "Sources" button is active, showing a list of source files. The selected file is "find_and_fix_memory_errors.cpp". The main pane displays the source code for this file, with line 170 highlighted: `drawing_area * drawing = new drawing_area(startx, totaly);`. The "Call Stack" pane on the right shows the call stack for the selected line, with the top entry being "find_and_fix_memory_errors.exe!operator() - find_and_fix_memory_errors.cp...". Below the main pane, the "Allocation site" is shown, with line 170 highlighted: `drawing_area * drawing = new drawing_area(startx, totaly);`. The "Call Stack" pane for the allocation site shows the same call stack as the main pane.

Intel Inspector XE 2016

Mismatched allocation/deallocation

Target Analysis Type Collection Log Summary Sources

Mismatched deallocation site - Thread thread_video (4596) (find_and_fix_memory_errors.exe!operator() - find_and_fix_memory_errors.cp...

find_and_fix_memory_errors.cpp Disassembly (find_and_fix_memory_errors.exe!0x46d6)

Call Stack

find_and_fix_memory_errors.exe!operator() - fi
find_and_fix_memory_errors.exe!run_body - pa
find_and_fix_memory_errors.exe!execute<class
find_and_fix_memory_errors.exe!execute - para
tbb_debug.dll!local_wait_for_all - custom_sc
tbb_debug.dll!local_spawn_root_and_wait - sc
tbb_debug.dll!spawn_root_and_wait - schedul
find_and_fix_memory_errors.exe!spawn_root_a
find_and_fix_memory_errors.exe!run - parallel

165 for (unsigned int i=0;i<=(mboxsize/(sizeof(unsigned int)));i++)
166 local_mbox[i]=0; //Memory Error: C declared arrays go from 0
167
168 for (int y = r.begin(); y != r.end(); ++y) {
169 {
170 drawing_area * drawing = new drawing_area(startx, totaly;
171 for (int x = startx ; x < stopx; x++) {
172 color_t c = render_one_pixel (x, y, local_mbox, serie
173 drawing->put_pixel(c);
174 }
175 free(drawing); //Memory Error: use delete instead of free
176 //delete drawing;

Allocation site - Thread thread_video (4596) (find_and_fix_memory_errors.exe!operator() - find_and_fix_memory_errors.cpp:170)

find_and_fix_memory_errors.cpp Disassembly (find_and_fix_memory_errors.exe!0x4613)

Call Stack

find_and_fix_memory_errors.exe!operator() - fi
find_and_fix_memory_errors.exe!run_body - pa
find_and_fix_memory_errors.exe!execute<class
find_and_fix_memory_errors.exe!execute - para
tbb_debug.dll!local_wait_for_all - custom_sche
tbb_debug.dll!local_spawn_root_and_wait - sc
tbb debug.dll!spawn root and wait - schedul


Call Stack

Quickly track down your Fortran issues!

Problems						?
ID ▲	Type	Sources	Modules	Object Size	State	
P1	Memory leak	nqueens_memory.f90	memory_issues.exe	64	New	

Code Locations: Memory leak						?
Description	Source	Function	Module	Object Size	Offset	Variable
Allocation site	nqueens_memory.f90:50	NQUEENS	memory_issues.exe	64		
48	!\$ nthreads = omp_get_max_threads()		memory_issues.exe!NQUEENS - nqueens			
49			memory_issues.exe!main			
50	allocate(correct_solution(16))		memory_issues.exe!_tmainCRTStartup			
51	correct_solution = (/ 1,0,0,1,2,10,4,40,92,352,72					
52						

Code Locations: Data race						?
Description	Source	Function	Module	Variable		
Read	nqueens_threading.f90:117	NQUEENS_ip_SETQUEEN	threading_issues.exe			
115	! Recursive routine to set a queen on the board		threading_issues.exe!NQUEENS_ip_SET			
116			threading_issues.exe!NQUEENS_ip_SET			
117	recursive subroutine setQueen (queens, row, col)		threading_issues.exe!NQUEENS_ip_SET			
118	implicit none		threading_issues.exe!NQUEENS_ip_SET			
119	integer, intent(inout) :: queens(:)		threading_issues.exe!NQUEENS_ip_SET			
Write	nqueens_threading.f90:117	NQUEENS_ip_SETQUEEN	threading_issues.exe			
115	! Recursive routine to set a queen on the board		threading_issues.exe!NQUEENS_ip_SET			
116			threading_issues.exe!NQUEENS_ip_SET			
117	recursive subroutine setQueen (queens, row, col)		threading_issues.exe!NQUEENS_ip_SET			
118	implicit none		threading_issues.exe!NQUEENS_ip_SET			
119	integer, intent(inout) :: queens(:)		threading_issues.exe!NQUEENS_ip_SET			

 **Locate Deadlocks and Data Races**

Target

Analysis Type

Collection Log

Summary

Problems					
ID ▲	Type	Sources	Modules	State	
P1	Data race	nqueens_threading.f90	threading_issues.exe	New	
P2	Data race	nqueens_threading.f90	threading_issues.exe	New	
P3	Data race	nqueens_threading.f90	threading_issues.exe	New	

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Filtering - Focus on What's Important

Example: See only the errors in one source file

Before – All Errors

Problems

ID	Type	Sources	State
P1	Mismatched alloc...	find_an ...	New
P2	Mismatched alloc...	api.cpp	New
P3	Memory leak	api.cpp	Confirmed
P4	Mismatched alloc...	video.c ...	Not fixed
P5	Mismatched alloc...	video.c ...	Not fixed
P6			

Filters

Severity: Error (55 item(s)), Warning (1 item(s))

Type: Invalid memory access (41 item(s)), Memory leak (1 item(s)), Memory not deallocated (11 item(s)), Mismatched allocation/dealloc... (2 item(s))

Source: api.cpp (21 item(s)), find_and_fix_memory_errors.cpp (3 item(s)), util.cpp (10 item(s)), video.cpp (21 item(s))

(1) Filter – Show only one source file

After – Only errors from one source file

Problems

ID	Type	Sources	State
P1	Mismatche...	find_an ...	New
P2	Memory leak	find_an ...	Confirmed
P3	Invalid me...	find_an ...	Deferred

Filters

Severity: Error (3 item(s))

Type: Invalid memory access (1 item(s)), Memory leak (1 item(s)), Mismatched allocation/dealloc... (1 item(s))

Source: All, find_and_fix_memory_errors.cpp (3 item(s))

State: Confirmed (1 item(s)), Deferred (1 item(s)), New (1 item(s))

Suppressed

(2) Error count drops

Tip: Set the “Investigated” filter to “Not investigated” while investigating problems. This removes from view the problems you are done with, leaving only the ones left to investigate.

Incrementally Diagnose Memory Growth

Intel® Inspector

As your app is running...

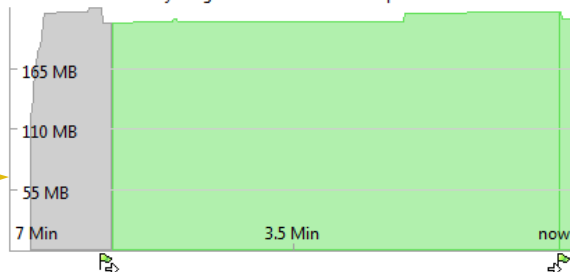
Memory usage graph
plots memory growth

Select a cause of
memory growth

See the code snippet
& call stack

Memory Used by Analysis Tool and Target Application

Last recorded memory usage before collection completed: 211 MB



Problems						
ID	Type	Sources	Modules	Object Size	State	
	Memory growth	gdiplus.dll:0x47240	gdiplus.dll	40960	New	
	Memory growth	find_and_fix_memory_errors.cpp:163	find_and_fix_memory_errors.exe	90108	Not fixed	
	Memory growth	find_and_fix_memory_errors.cpp:163	find_and_fix_memory_errors.exe	1802160	Not fixed	
	Memory growth	find_and_fix_memory_errors.cpp:163	find_and_fix_memory_errors.exe	30036	Not fixed	
	Memory growth	find_and_fix_memory_errors.cpp:163	find_and_fix_memory_errors.exe	1621944	Not fixed	
	Memory growth	find_and_fix_memory_errors.cpp:170	find_and_fix_memory_errors.exe	40	Not fixed	

Code Locations: Memory growth				
Description	Source	Function	Module	Object Size
Allocation site	find_and_fix_memory_errors.cpp:163	operator()	find_and_fix_memory_errors.exe	90108
<pre>161 unsigned int serial=1; 162 unsigned int mboxsize = sizeof(unsigned int)*(max_objectid() + 163 unsigned int * local_mbox = (unsigned int *) malloc(mboxsize); 164 165 for (unsigned int i=0;i<=(mboxsize/(sizeof(unsigned int)));i++</pre>				

Speed diagnosis of difficult to find heap errors

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Automate Regression Analysis

Command Line Interface

inspxe-cl is the command line:

- **windows:** C:\Program Files\Intel\Inspector XE \bin[32|64]\inspxe-cl.exe
- **Linux:** /opt/intel/inspector_xe/bin[32|64]/inspxe-cl

Help:

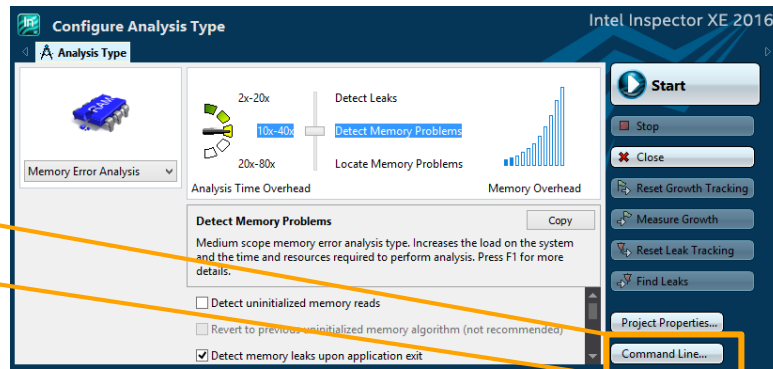
```
inspxe-cl -help
```

Set up command line with GUI

Command Line...

Command examples:


1. `inspxe-cl -collect-list`
2. `inspxe-cl -collect ti2 -- MyApp.exe`
3. `inspxe-cl -report problems`




Send results file to developer to analyze with the UI

Compare results and see what has changed


Ideal for regression testing


 **Compare Results**


 **Choose two results of the same analysis type**
Compare two results to identify issues that exist in one but not the other, or that still exist in both.






Result 1:


Result 2:



 **Compare**

 **Close**

 **Compared Result**

  **Target**  **Analysis Type**  **Collection Log**  **Summary**

Problems 

ID		Type	Sources	Modules	State
P1		Data race	find_and_fix_threading_errors.cpp	find_and_fix_threading_errors.exe	Both
P2		Data race	winvideo.h	find_and_fix_threading_errors.exe	Both

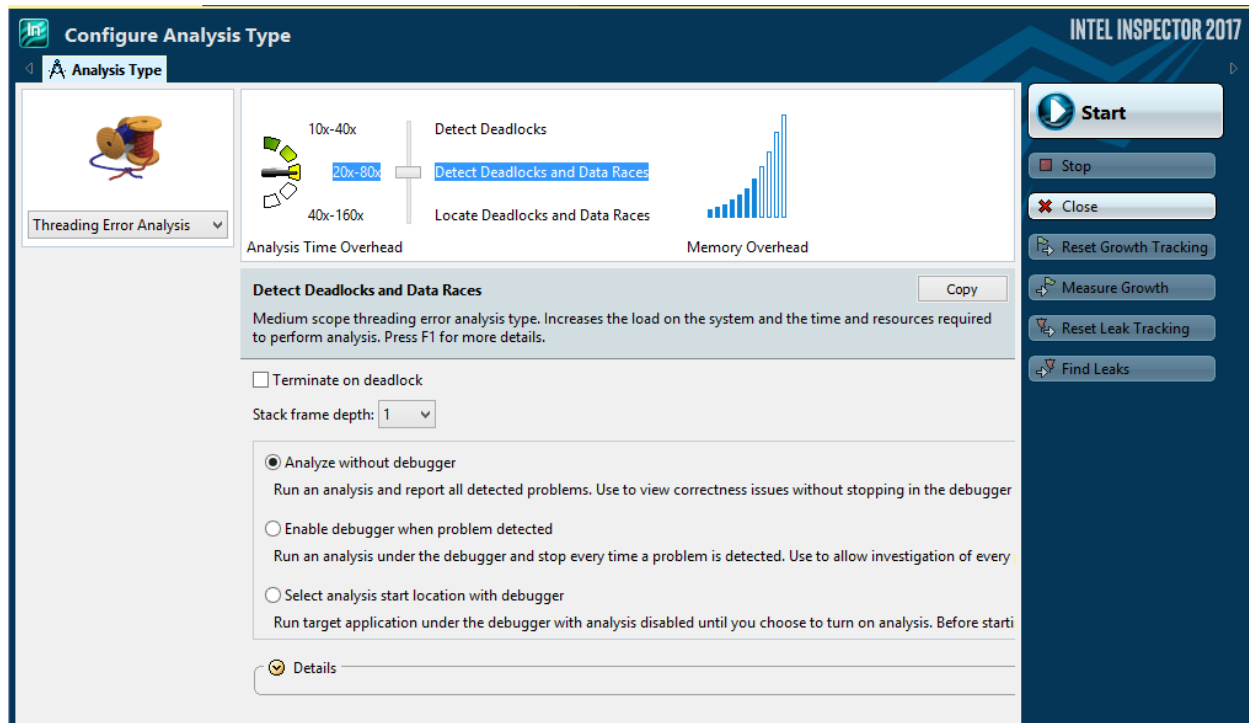
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Find problems quicker!

Interactive debugging support



3 debugging modes supported

1. Analyze without debugger
2. Enable debugger when problem detected
3. Start analysis when a debug breakpoint is hit.

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Intuitive problem solving using debugger integrations

Microsoft Visual Studio*
and GNU gdb* or Intel®
Debugger (on Linux*)

```
    /// Refresh screen picture
    bool video::next_frame()
    {
        if(!running) return false;
        g_updates++; // Fast but inaccurate counter. The data race here is benign
        if(!threaded) while(loop_once(this));
        else if(g_handles[1]) {
            SetEvent(g_handles[1]);
            YIELD_TO_THREAD();
        }
        return true;
    }
}
```

Problem Details

Source Intel Inspector Disable Breakpoint Re-enable Breakpoints

Data race at data location 0x135dc for threads 16208 and TBB Worker Thread

Description ▲	Source	Function	Module
+ Read	winvideo.h:270	next_frame	find_and_fix_threading_errors.exe
+ Write	winvideo.h:271	next_frame	find_and_fix_threading_errors.exe

Problem Deta... Compiler Inli... Compiler Opt... Call Stack Breakpoints Output

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Break At Just The Right Time

Intel® Inspector - Memory & Thread Debugger

Memory Errors

Problems			
ID ▲	Type	Sources	
P1	Mismatched allocation/deallocation		
P2	Memory leak		
P3	Invalid memory access		
	Invalid memory access		
P4	Memory growth		
P5	Memory growth		
P6	Memory growth		

View Source

Edit Source

Copy to Clipboard

Explain Problem

Create Problem Report...

Debug This Problem

Threading Errors

Problems			
ID ▲	Type	Sources	Modules
P1	Data race	winvideo.h	
	Data race	winvideo.h:270	
	Data race	winvideo.h:270	
	Data race	winvideo.h:201	
	Data race	winvideo.h:202	
	Data race	winvideo.h:202	

View Source

Edit Source

Copy to Clipboard

Explain Problem

Create Problem Report...

Debug This Problem

Break into the debugger just before the error occurs.

Examine the variables and threads.

Diagnose the problem.

Save time. Find and diagnose errors with less effort.

Work Smarter & Faster

Intel® Inspector - Memory & Thread Debugger

Precise Error Suppression

```
Suppression = {  
    Name = "Example";  
    Type = { uninitialized_memory_access }  
    Stacks = {  
        {  
            mod=a.out, func=update_x;  
            func=main;  
        }  
    }  
}
```

Precise, easy to edit, team shareable.

Choose which stack frame to suppress.

Eliminate the false, not the real errors.

Pause/Resume Collection

```
__itt_suppress_push(__itt_suppress_threading_errors);  
/* Any threading errors here are ignored */  
__itt_suppress_pop();  
/* Any threading errors here are seen */
```

Speed-up analysis by limiting its scope.

Analyze only during the execution of the suspected problem.

Find and diagnose errors with less effort.

Productive Memory & Threading Debugger

Intel® Inspector

	Memory Analysis	Threading Analysis
View Context of Problem		
Stack	✓	✓
Multiple Contributing Source Locations	✓	✓
Collapse multiple “sightings” to one error (e.g., memory allocated in a loop, then leaked is 1 error)	✓	✓
Suppression, Filtering, and Workflow Management	✓	✓
Visual Studio* Integration (Windows*)	✓	✓
Command line for automated tests	✓	✓
Time Line visualization	✓	✓
Memory Growth during a transaction	✓	
Trigger Debugger Breakpoint	✓	✓

Easier & Faster Debugging of Memory & Threading Errors

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WHAT'S NEW

New Features

Support for Intel® Xeon Phi™ processor (codename: Knights Landing)

Support for C++11 synchronization primitives during threading analysis

Variable name detection for threading analysis

Variable name detection for threading analysis

The screenshot displays the Intel Inspector 2017 interface, specifically the 'Detect Deadlocks and Data Races' tool. The 'Summary' tab is active, showing a list of detected problems. Two data race issues are identified: P1 and P2. P1 is a data race involving 'find_and_fix_threading_errors.cpp' and 'find_and_fix_threading_errors.exe'. P2 is a data race involving 'winvideo.h' and 'find_and_fix_threading_errors.exe'. The 'Filters' panel on the right shows the severity, type, source, module, state, and suppression status of the detected issues. The 'Code Locations: Data race' panel at the bottom shows the source code for the detected data race, highlighting the problematic lines. The 'Timeline' panel on the right shows the execution timeline, including the 'read_video (14232)' and 'BB Worker Thread (12516)'.

Detect Deadlocks and Data Races

Target Analysis Type Collection Log Summary

Problems

ID	Type	Sources	Modules	State
P1	Data race	find_and_fix_threading_errors.cpp	find_and_fix_threading_errors.exe	New
	Data race	find_and_fix_threading_errors.cp ...	find_and_fix_threading_errors.exe	New
	Data race	find_and_fix_threading_errors.cp ...	find_and_fix_threading_errors.exe	New
	Data race	find_and_fix_threading_errors.cp ...	find_and_fix_threading_errors.exe	New
	Data race	find_and_fix_threading_errors.cp ...	find_and_fix_threading_errors.exe	New
P2	Data race	winvideo.h	find_and_fix_threading_errors.exe	New

Filters

Severity	Count
Error	2 item(s)

Type	Count
Data race	2 item(s)

Source	Count
find_and_fix_threading_errors.cpp	1 item(s)
winvideo.h	1 item(s)

Module	Count
find_and_fix_threading_errors.exe	2 item(s)

State	Count
New	2 item(s)

Suppressed	Count
Not suppressed	2 item(s)

Investigated	Count
Not investigated	2 item(s)

Code Locations: Data race

Description	Source	Function	Module	Variable
Write	find_and_fix_threading_errors.cpp:105	render_one_pixel	find_and_fix_threading_errors.exe	color
<pre>103 primary.scene = sscene; 104 105 col=trace(sprimary); //Threading Error: col is a global variable 106 //2 ways to fix this threading error 107 // 1) Make col a local variable</pre>				
Write	find_and_fix_threading_errors.cpp:105	render_one_pixel	find_and_fix_threading_errors.exe	color
<pre>103 primary.scene = sscene; 104 105 col=trace(sprimary); //Threading Error: col is a global variable 106 //2 ways to fix this threading error 107 // 1) Make col a local variable</pre>				

Timeline

- read_video (14232)
- BB Worker Thread (12516)

Memory & Threading Debugger Saves Time

Intel® Inspector

"We struggled for a week with a crash situation, the corruption was identified but the source was really hard to find. Then we ran **Intel® Inspector** and immediately found the array out of bounds that occurred long before the actual crash. We could have saved a week!"

*Mikael Le Guerroué,
Senior Codec Architecture Engineer,
Envivio*

"**Intel® Inspector** is quite fast and intuitive compared to products we have used in the past. We can now run our entire batch of test cases (~750) which was not feasible previously. **Intel® Inspector** easily completed tests that failed due to lack of virtual memory on another product."

*Gerald Mattauch
Senior Software Developer
Siemens AG, Healthcare Sector*

Intel® Inspector has dramatically sped up our ability to find/fix memory problems and track down difficult to isolate threading errors before our packages are released to the field.

*Peter von Kaenel, Director,
Software Development,
Harmonic Inc.*

[More Case Studies](#)

Call to Action

Modernize your Code

- To get the most out of your hardware, you need to modernize your code with vectorization and threading.
- Taking a methodical approach such as the one outlined in this presentation, and taking advantage of the powerful tools in Intel® Parallel Studio XE, can make the modernization task dramatically easier.

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Notice revision #20110804

