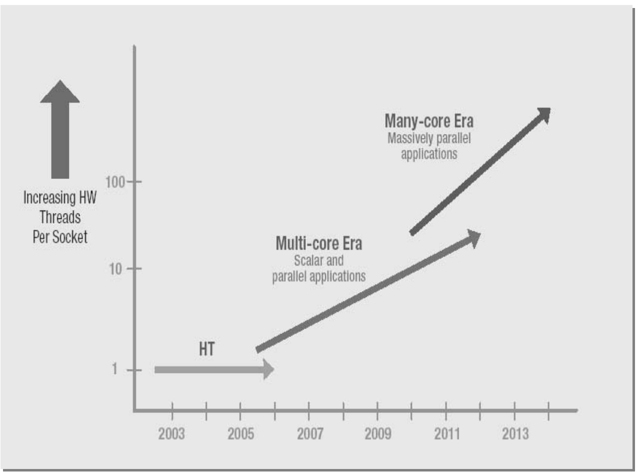
Improving Software Performance and Correctness with Intel® Threading Tools

Intel
Software and Solutions Group (SSG)
Developer Products Division (DPD)

Intel® Processor and Platform Evolution for the Next Decade



Source: "Platform 2015: Intel® Processor and Platform Evolution for the Next Decade"

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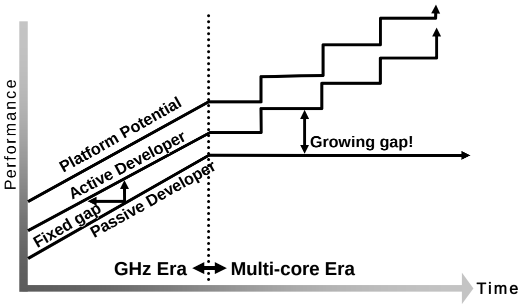
Paths to taking advantage of Multi-core Processors

- **Do Nothing:**
  - Background tasks benefit from more compute resources
  - Limited potential for single-application performance



- **Process-level parallelism**
  - Can be cumbersome to work on a shared data set
- **Application threading for performance:**
  - Use native threads or threading abstraction libraries
  - OpenMP is a cross-platform standard useful for quickly parallelizing with domain decomposition
  - Intel software tools can aid developer in efficiently threading

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A Generic Development Cycle

Analyze

–VTune™ Performance Analyzer

Design (Introduce Threads)

–Intel® Performance libraries: IPP and MKL

–OpenMP* (Intel® Compiler)

–Explicit threading (Win32*, Pthreads*)

–Intel® Threading Building Blocks

Debug for correctness

–Intel® Thread Checker

–Intel® Debugger

Tune for performance

–Intel® Thread Profiler

–VTune™ Performance Analyzer

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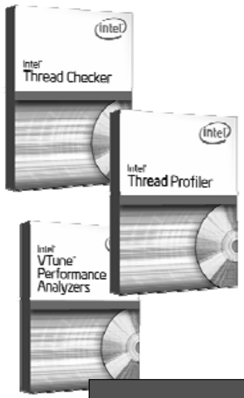
*Other names and brands may be claimed as the property of others

Multi-core Software Tools

How can we help more developers use parallelism?



Intel® Thread Checker
pinpoints latent threading errors

Intel® Thread Profiler
Insight into threaded application/lock level performance

Intel® VTune™ Performance Analyzer
Insight into system level performance

We help make it easier

Intel® Thread Checker

Create Threads Faster

Key Features

- Detects challenging data races and deadlocks
- Pinpoints errors to the source code line
- Works on standard debug builds without recompiling
- Recommends modules to instrument by usage (windows* product)
- Scriptable interface for test environment integration
- Supports 32 and 64-bit applications

Thread Checker: Overview

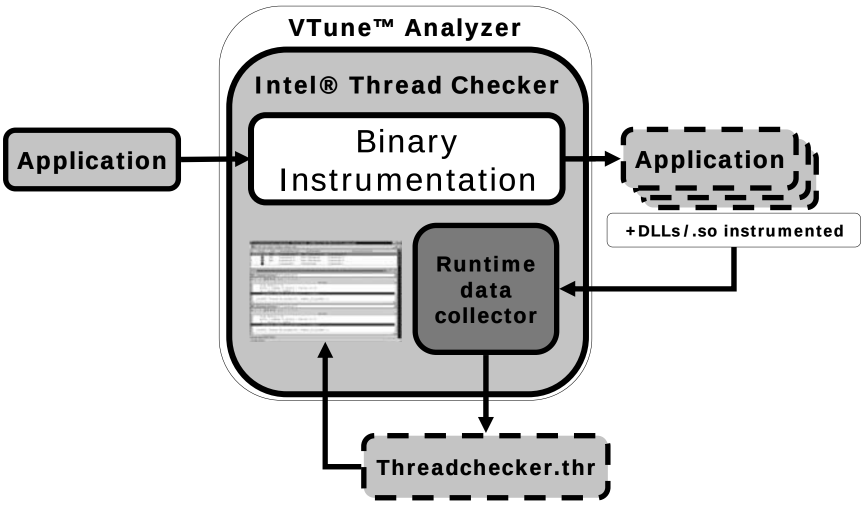
Features & Benefits

- Pinpoint the function, context, line, variable, and call stack in the source code to aid analysis and repair of bugs
- Identify nearly impossible-to-find data races and deadlocks using an advanced error detection engine
- Instrumental for effective design of threaded applications
- Errors do not need to actually occur to be detected

Platforms

- Supports Windows* threads or OpenMP* applications on Windows for IA32/EM64T
- Supports POSIX* threads or OpenMP* for applications on Linux for IA32/EM64T/IPF from a Windows host
- Command-line-only version for Linux is in beta

Thread Checker Phases



Thread Checker Analysis

Dynamic analysis as software runs

- Data (workload)-driven execution
- If code path not executed, no analysis of path

Includes monitoring of:

- Thread and synchronization API's used
- Thread execution order
  - Scheduler impacts results
- Memory accesses between threads

Thread Checker: Before You Start

Instrumentation: Background

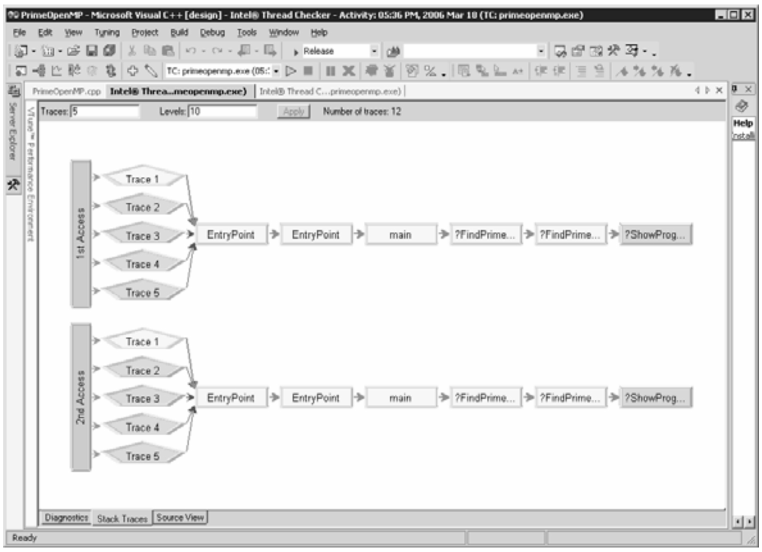
- Adds calls to library to record information
  - Thread and synchronization API's, memory accesses
- Increases execution ***time*** and ***size***

Use *small* data sets (workloads)

- Execution time and space is **expanded**
- Multiple runs over different paths yield best results

Workload selection is important!

Thread Checker Views



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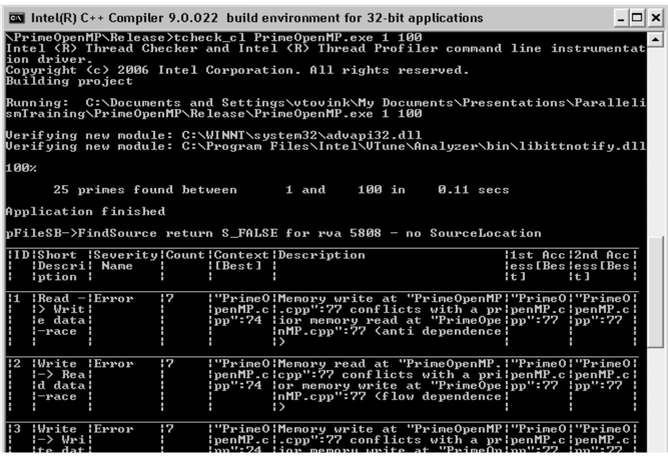
Thread Checker Command-Line

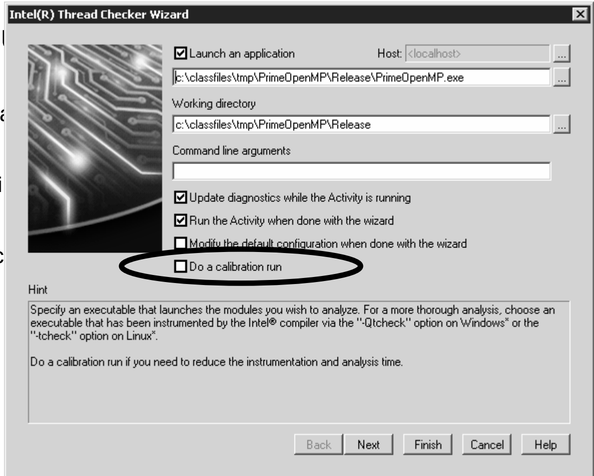


Thread Checker can be integrated into automatic test system

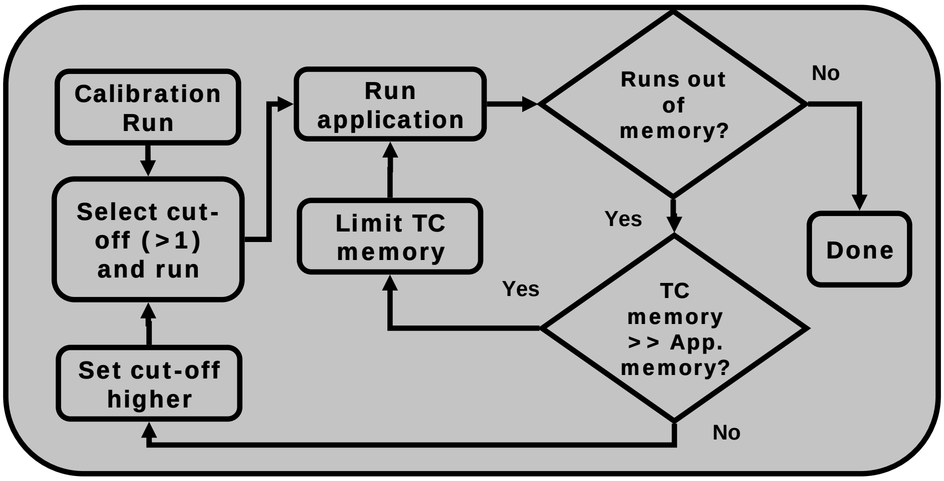
Getting Applications to Run

Solution - U

- **Step 0:**
  - Use sma
- **Step 1:**
  - Use cali
- **Step 2:**
  - Select c



Selective Instrumentation Using Calibration



Dealing with High Diagnostics Count

Where do you begin debugging?

Are all the diagnostic messages equally important/serious?

Steps:

- Add “1st Access” column
- Group by “1st Access”
- Sort by “Short Description” column

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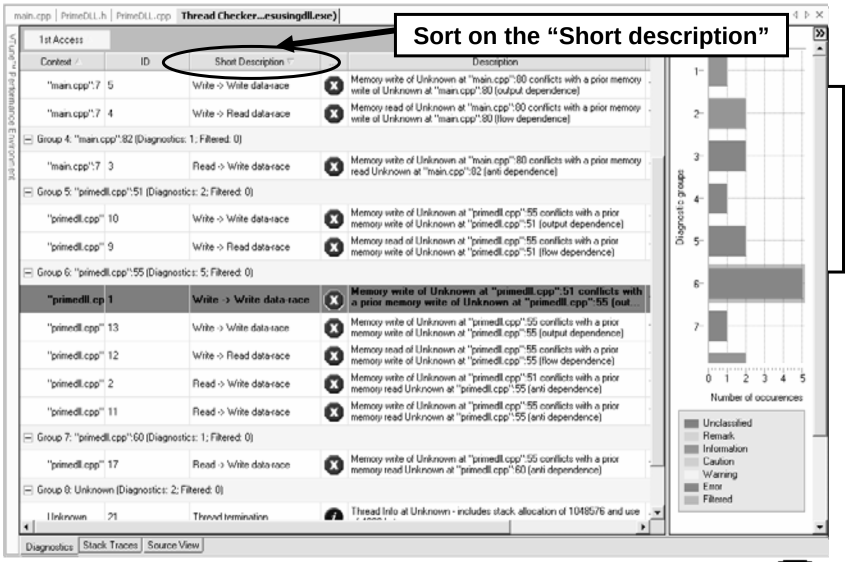
Dealing with High Diagnostics Count



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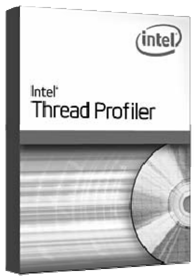
Thread Checker Summary

- Thread Checker functions as a design, debugging, and quality aid
  - Automatically detects hard-to-find data races and deadlocks in multi-threaded applications
- Workload selection is extremely important for successful runs
  - Default configuration works well for unit tests; larger fully integrated applications require the use of calibration run

Reduce time to market for threaded applications by speeding up the development process

Intel® Thread Profiler 3.0 for Windows*

Optimize Threads Faster



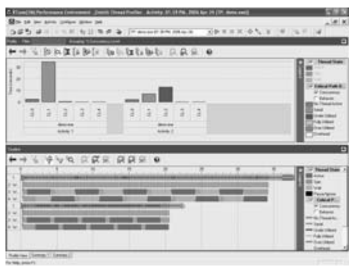
Key Features:

Understand Threading Behavior

- View potential core utilization

Optimize Threading Performance

- Fully utilize available cores
- Identify which synchronization objects are contended and which waits actually affect performance
- Highlight workload imbalance
- Pinpoints issues to the source code

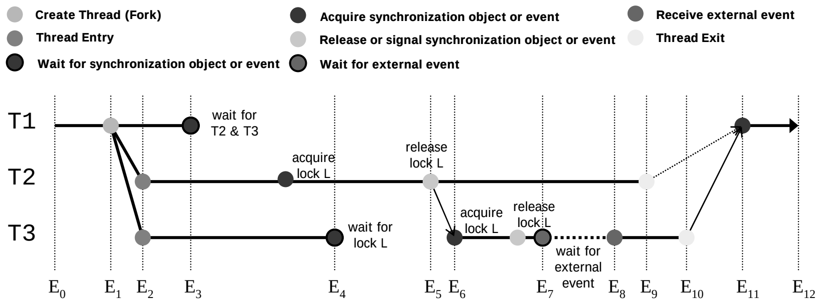


Supported Environments:

- Supports 32 and 64-bit applications
- Native thread-API on Microsoft Windows* (Win32 Threads)
- Native thread-API on Linux* (PThreads)
- OpenMP* threads
- Intel's new parallel programming model
- Graphical visualization available on Windows*

Thread Profiler Execution Flow

- •Thread Profiler instruments system API calls
- •Run-time engine intercepts API calls and records events when instrumented application is running
  - – calling thread ID, time, duration, sync object ID, call-stack
- •In the end of the program run TP data file gets produced
- •Thread Profiler GUI visualizes threads behavior



System APIs – Windows* Threads and POSIX* threads

- Thread and Process Control APIs
  - – Fork, Create, Terminate, Suspend, Resume, Exit
- Synchronization APIs
  - – Mutexes, Critical Sections, Locks, Semaphores, Thread Pools, Timers, Messages, APCs, Events, Condition Variables
- Blocking APIs
  - – Sleeping, Timeouts
  - – I/O: Files, Pipes, Ports, Messages, Network, Sockets
  - – User I/O: Standard, GUI, Dialog Boxes

* POSIX* threads API is supported for Linux apps

User Synchronization

If custom synchronization is used, Thread Profiler provides an API for users to instrument user synchronization.

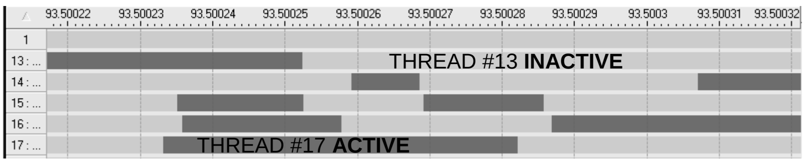
```
__itt_notify_sync_prepare( &spin );
while( wait for spin ) {
  if( timeout ) {
        __itt_notify_sync_cancel( &spin );
        return;
  }
}
__itt_notify_sync_acquired( &spin );

do stuff;

__itt_notify_sync_releasing( &spin );
release spin;
```


Thread Profiler: Terminology

Thread Activity

- Types of thread activity
  - Thread active: runs or ready to run
  - Thread inactive: waits for sync object, blocks on external event
- Thread Profiler view

Time ➔



- Rationale
  - You don't want to have too many threads active and competing for cores
  - You want to keep all cores busy with work when number of active threads equals to number of cores
  - Thread Profiler collects call-stack for wait and blocking APIs – you can locate the problem area in the source file

Transitions

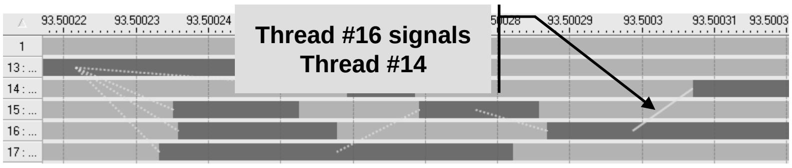
- Represents "signal" sent by one thread to another by releasing synchronization object
- Attributes:
  - Signaling and receiving thread IDs
  - Overhead – time spent between "send" and "receive" events
  - "Send" and "receive" events call-stacks

Time ➔

0: Thread 1 starts	0: Thread 2 starts
1: Thread 1 acquires Critical Section	1: Thread 2 processes private data
2: Thread 1 processes shared data	2: Thread 2 attempts to acquire Critical Section and blocks
3: Thread 1 releases Critical Section	3: Thread 2 acquires Critical Section
4: …	4: Thread 2 processes shared data
	5: Thread 1 releases Critical Section

Transitions (cont.)

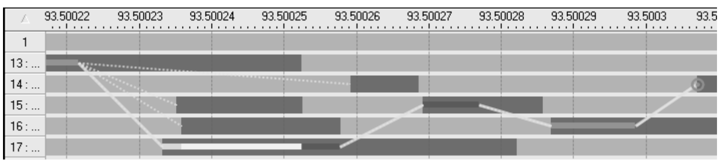
- Types of transitions
  - Contended: receiving thread had to wait for the signal
  - Uncontended: thread acquired the sync object without contention
- Thread Profiler view



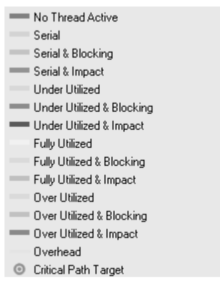
- Rationale
  - Thread Profiler collects call-stack for transitions – you can locate the problem area in the source file
  - Thread Profiler attributes transition overhead to the specific sync object – you can find the most expensive sync objects
  - Thread Profiler visualize transitions – you can spot the area with the most excessive synchronization and focus your analysis effort on it

Critical Path

- Definition
  - Longest execution flow; emphasizes segments of the threaded program that are worth optimizing
  - Characterized behavior of active threads
- Thread Profiler view

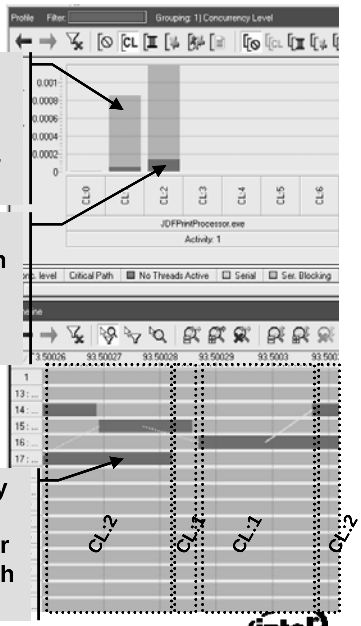


- Rationale
  - Useful for throughput analysis
  - Helps understand threads behavior



Concurrency Level (CL)

- Definition
  - Number of active threads
- Rationale
  - Thread Profiler summarizes threads activity information and groups it by concurrency levels – you can understand overall CPUs utilization
  - Thread Profiler Timeline and Profile view are synchronized – you can zoom-in and filter data and get from summary view into detailed view
  - CL grouping (like any other view) may be combined with critical path data – you can view threaded behavior at a higher level

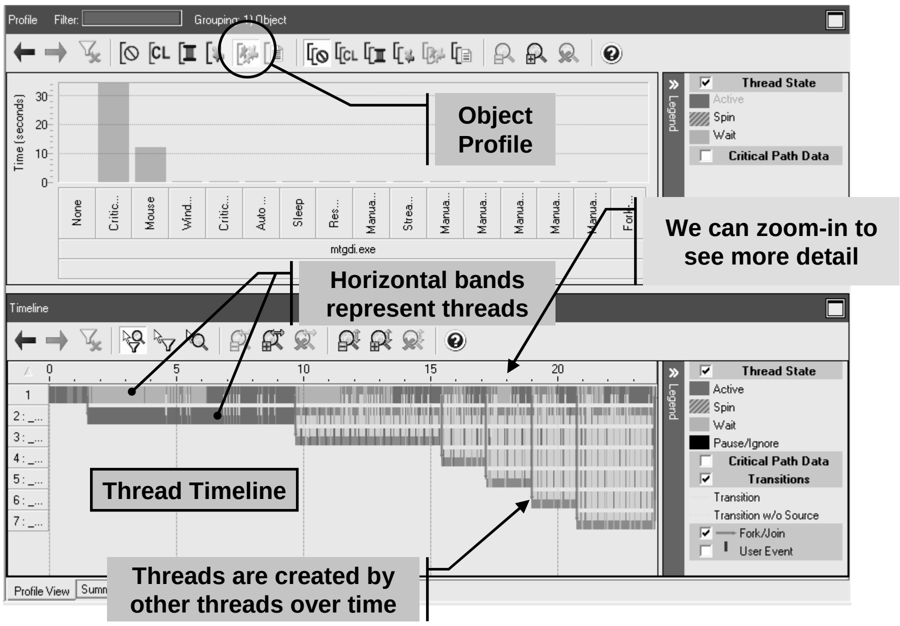


Groupings and Filtering

- Profile View
  - Grouping by Concurrency Level
  - Grouping by Threads
  - Grouping by Objects
  - Grouping by Source Locations
- Timeline View
  - Manual filtering of any region of interest
  - Synchronized automatic filtering: double-click on any bar at Profile View and Timeline data gets filtered

Understand Threading Behavior

Object Profile and Thread Timeline



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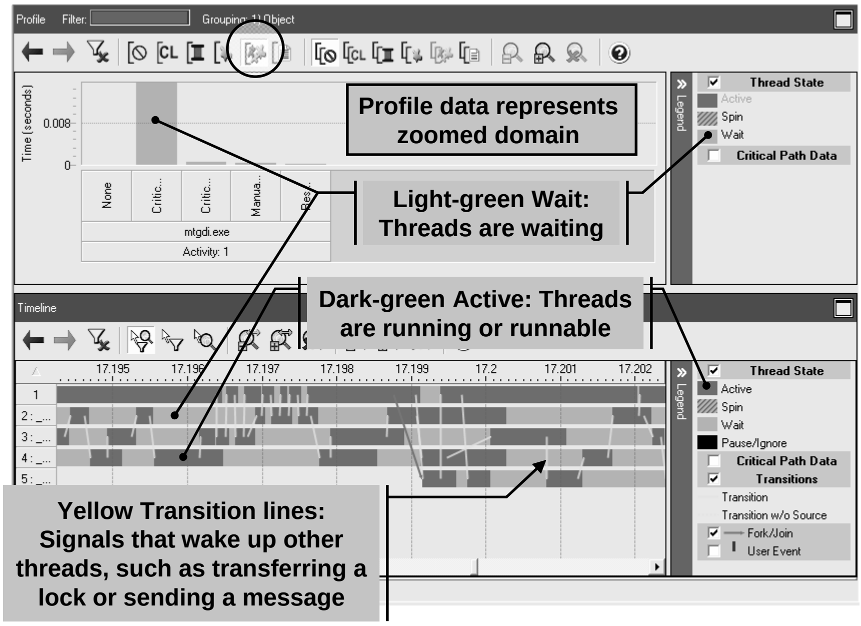
Zoom-in for more detail



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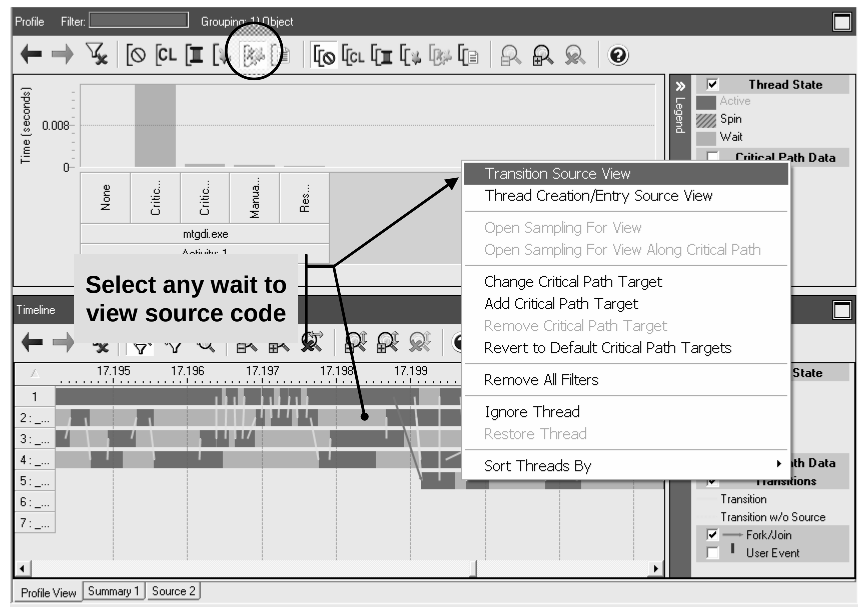
View source for any thread wait



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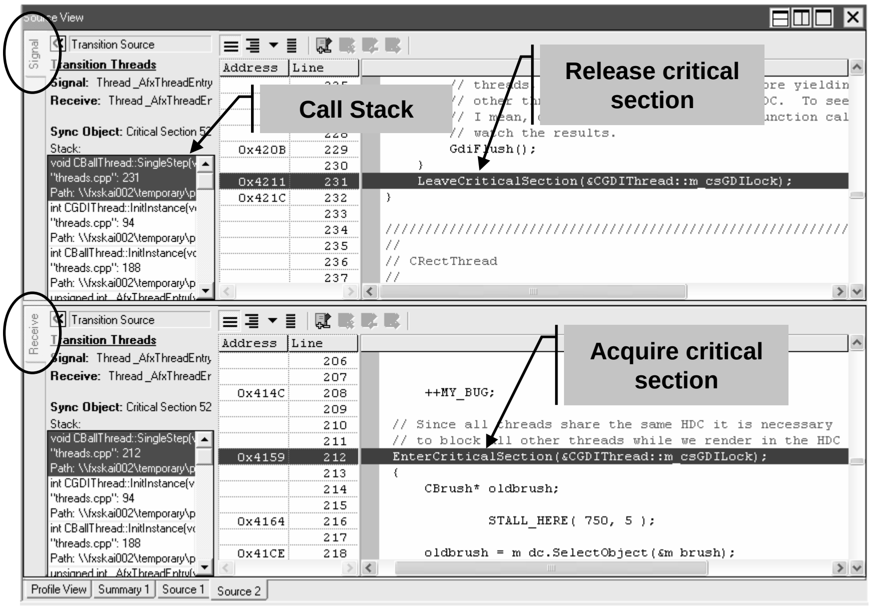
Synchronization source view



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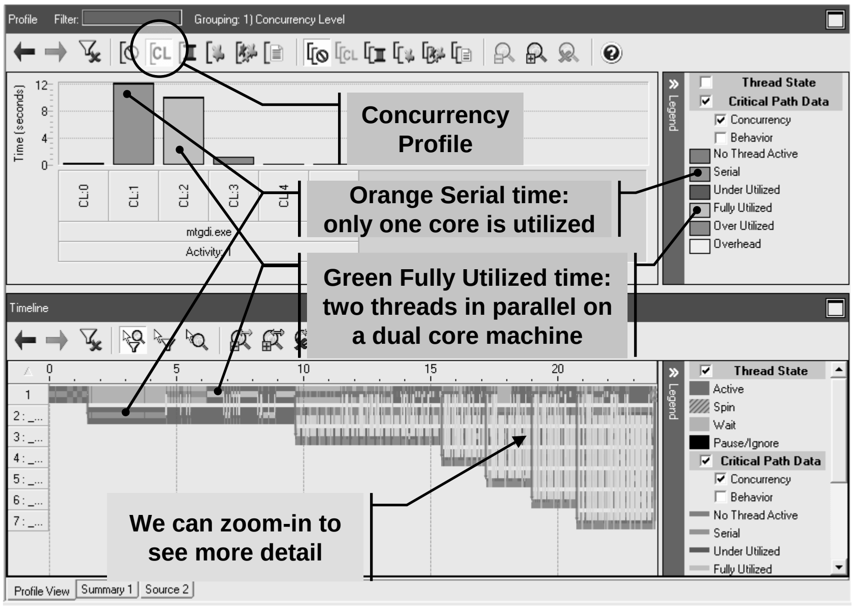
Optimize
Threading Performance

Concurrency Profile and Thread Timeline



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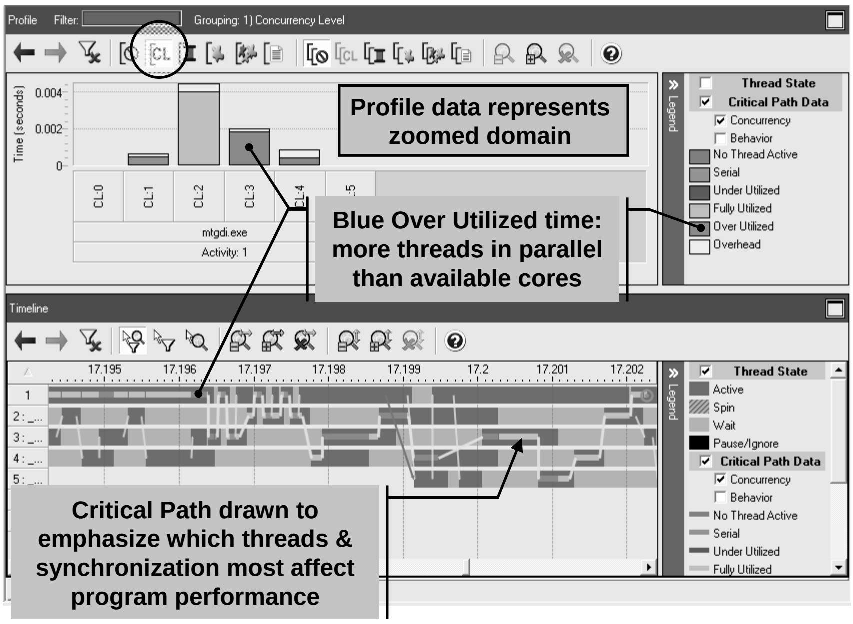
Zoom-in for more detail



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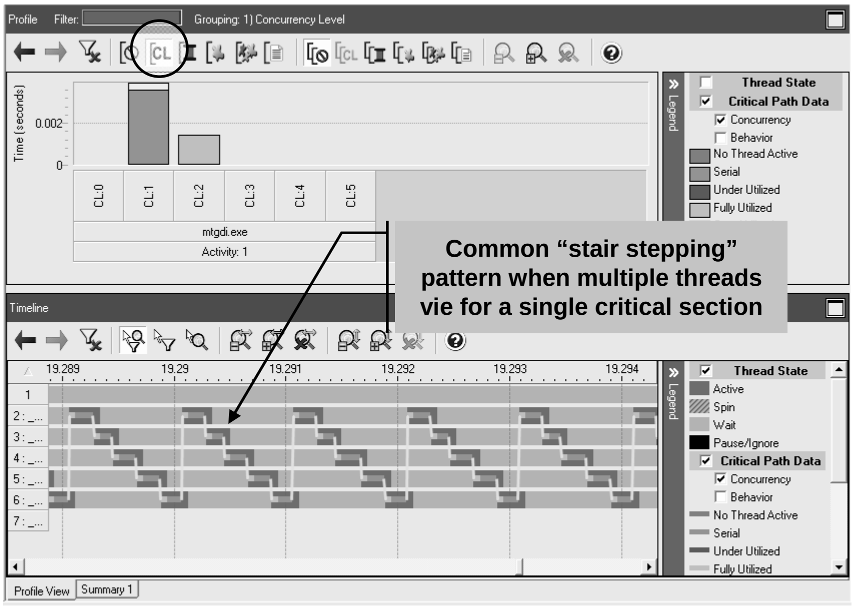
Example lock “stair stepping” pattern



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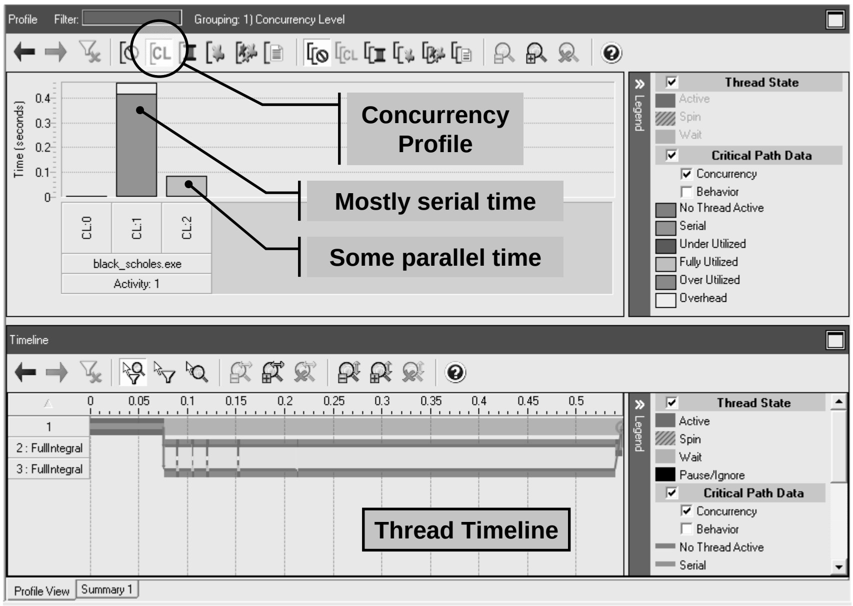
Example Performance Analysis

Numerical Simulation

View initial Thread Profiler results



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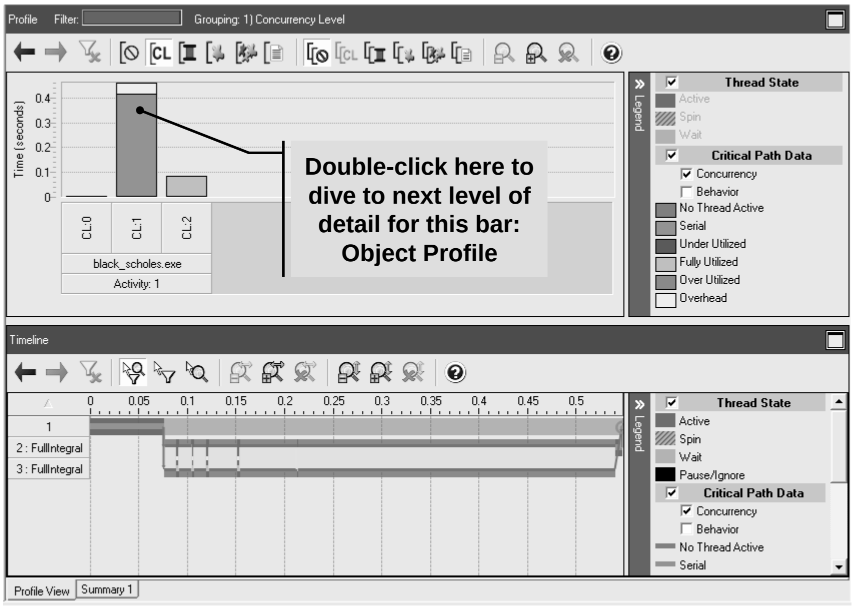
Dive for more detail about serial time



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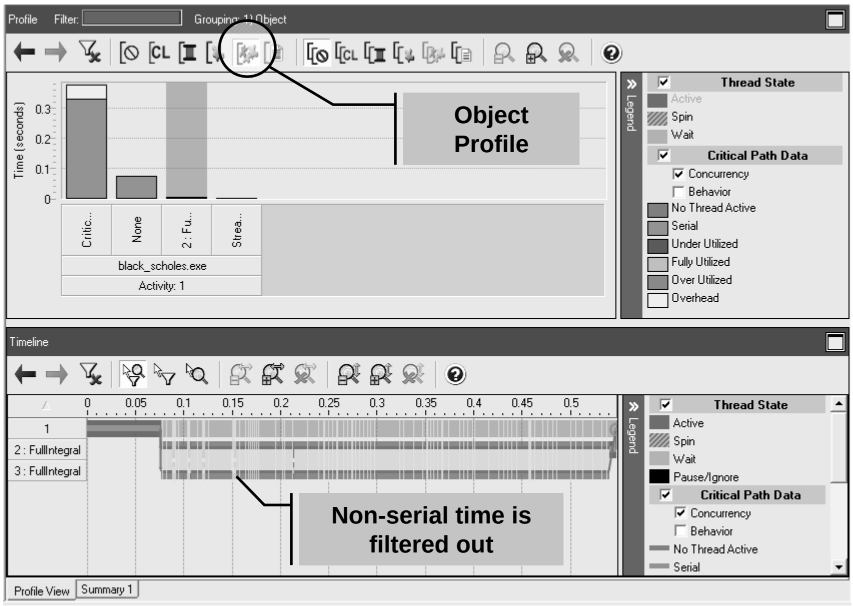
Object Profile for serial time



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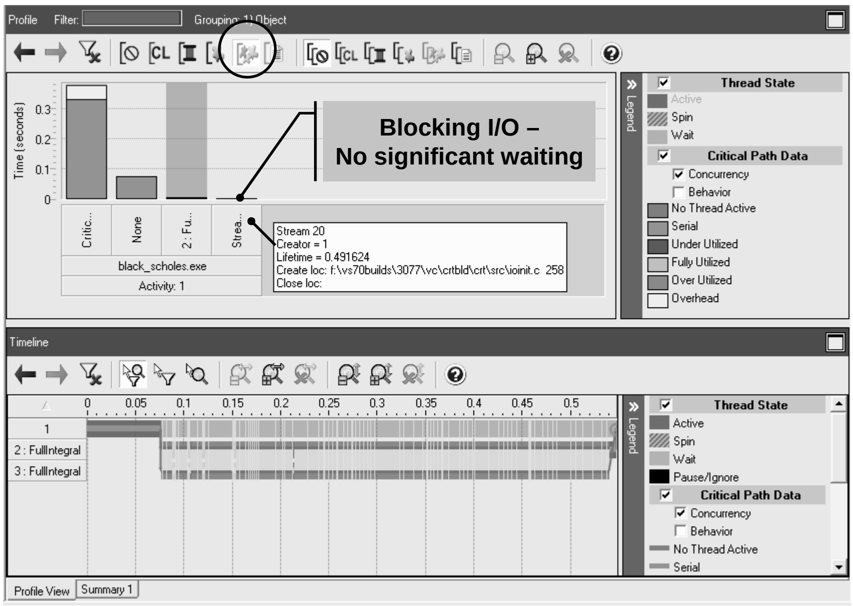
Object Profile – Blocking I/O



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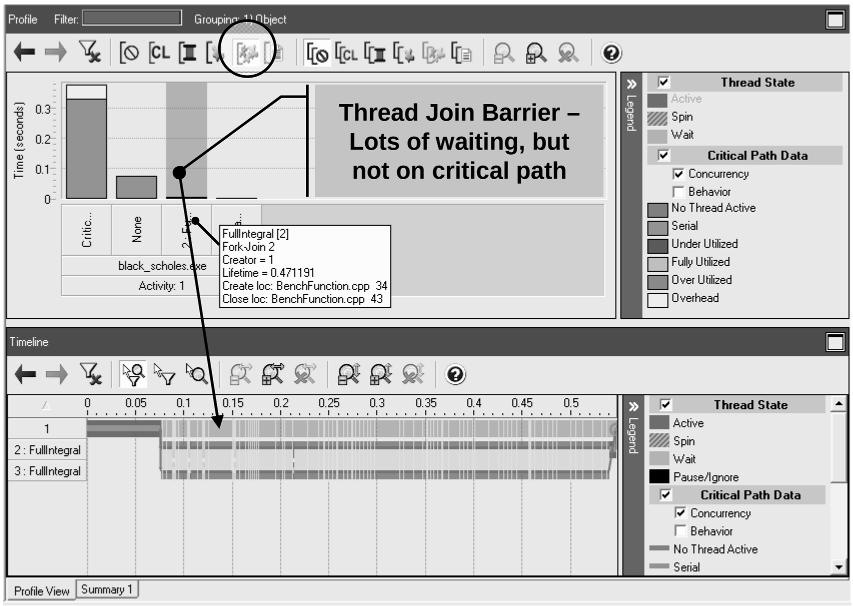
Object Profile – Thread Join Barrier



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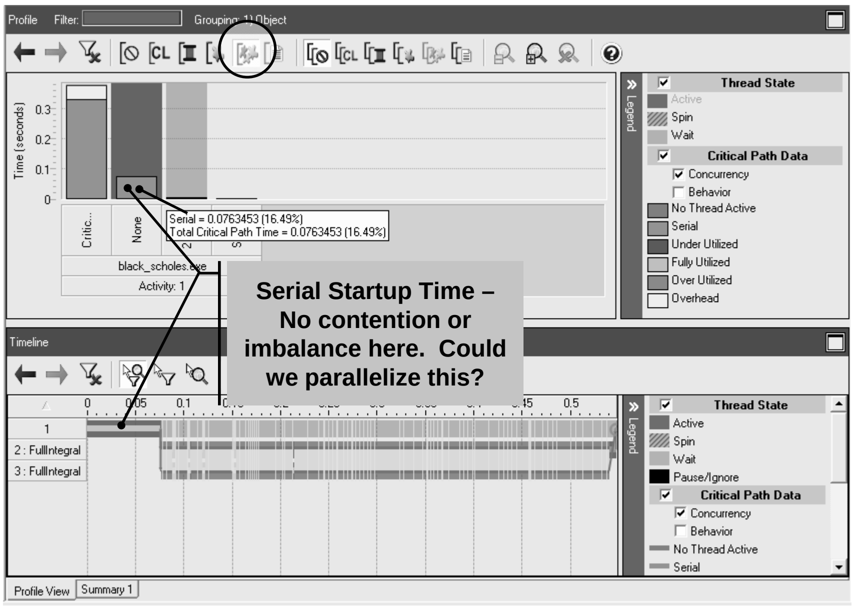
Object Profile – Serial Startup



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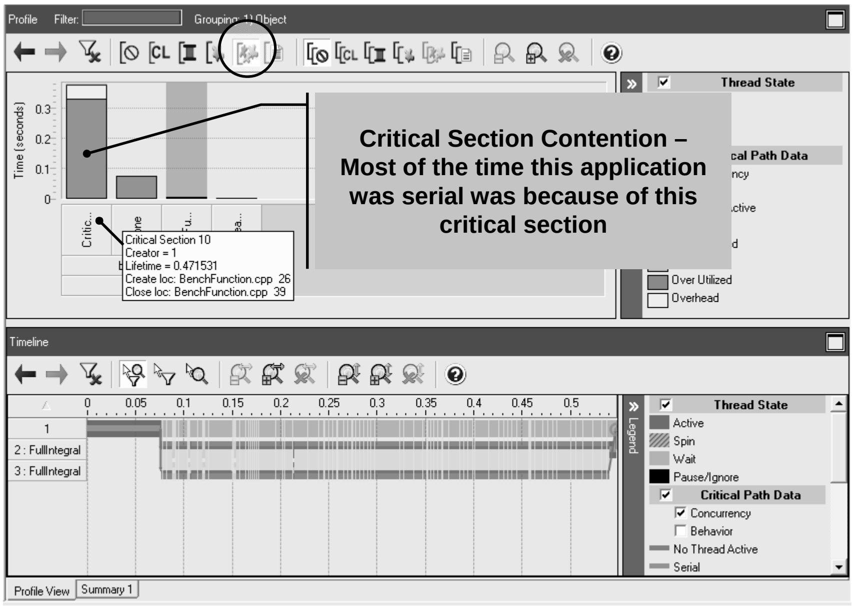
Object Profile – Critical Section



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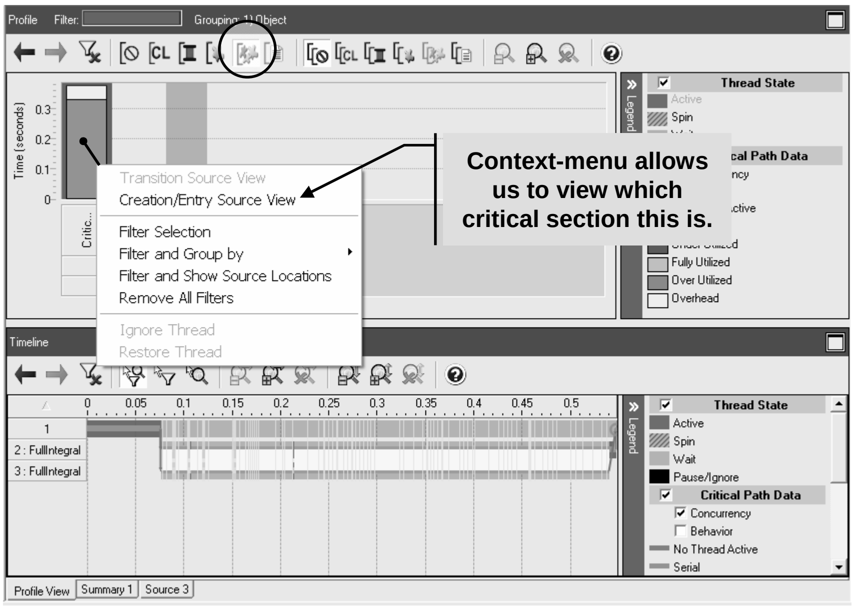
View source for object creation point



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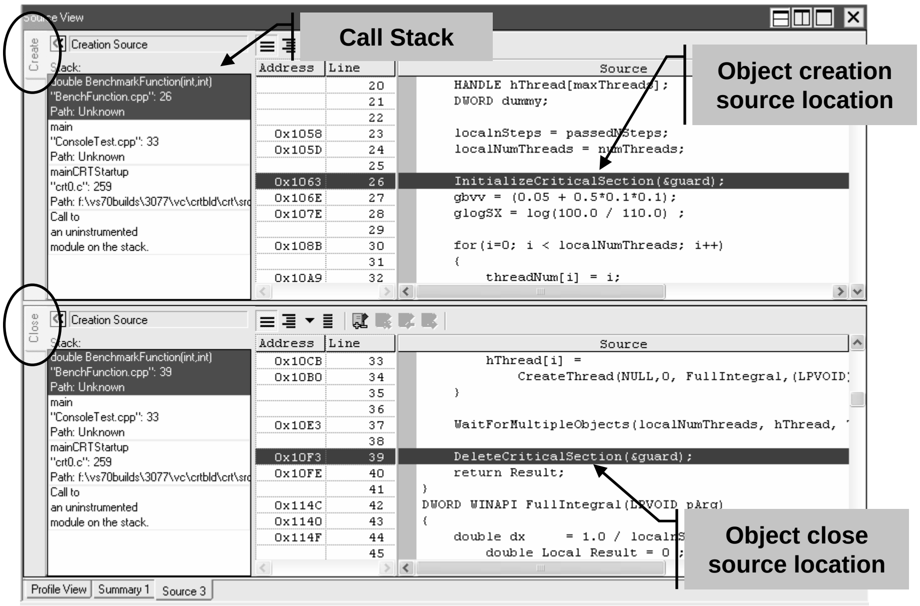
Object create / close source view



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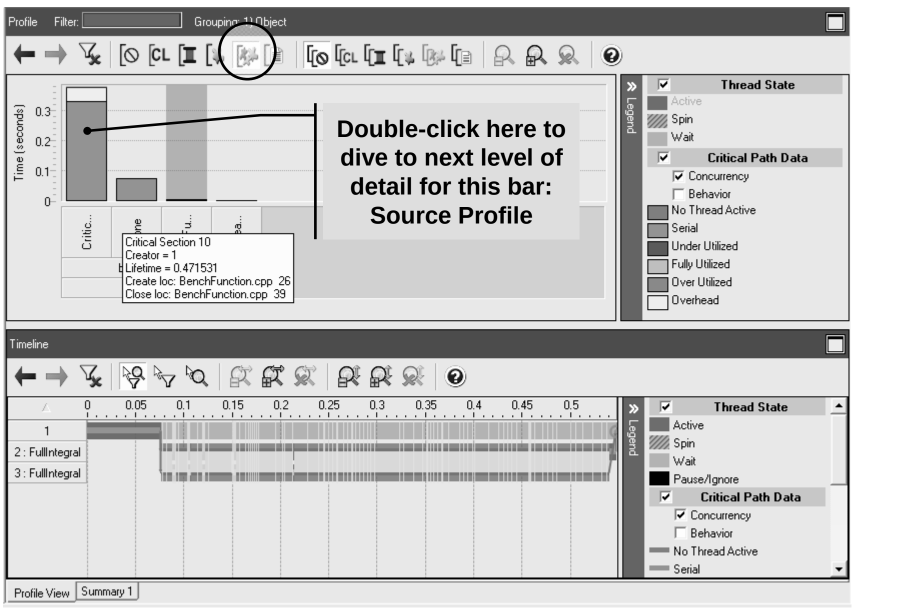
Dive for more detail about this object



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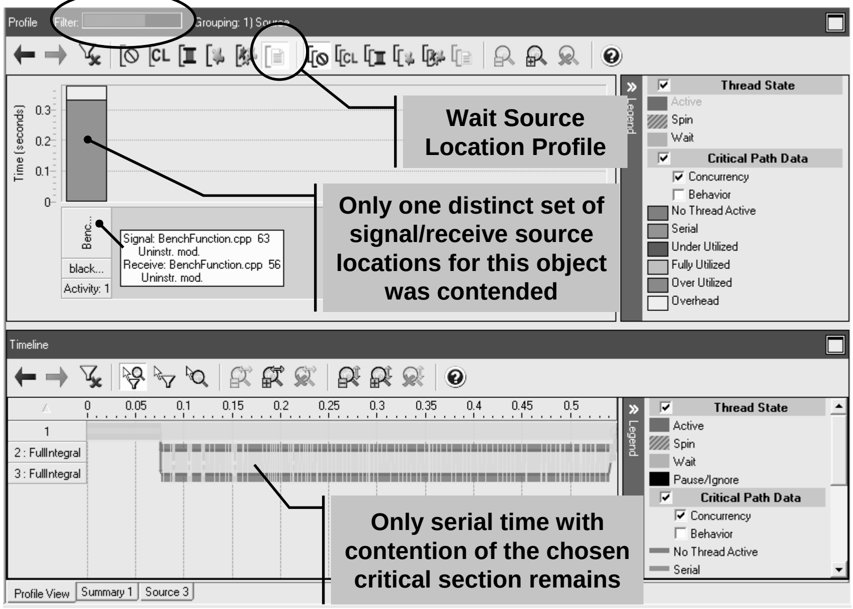
Wait source location profile



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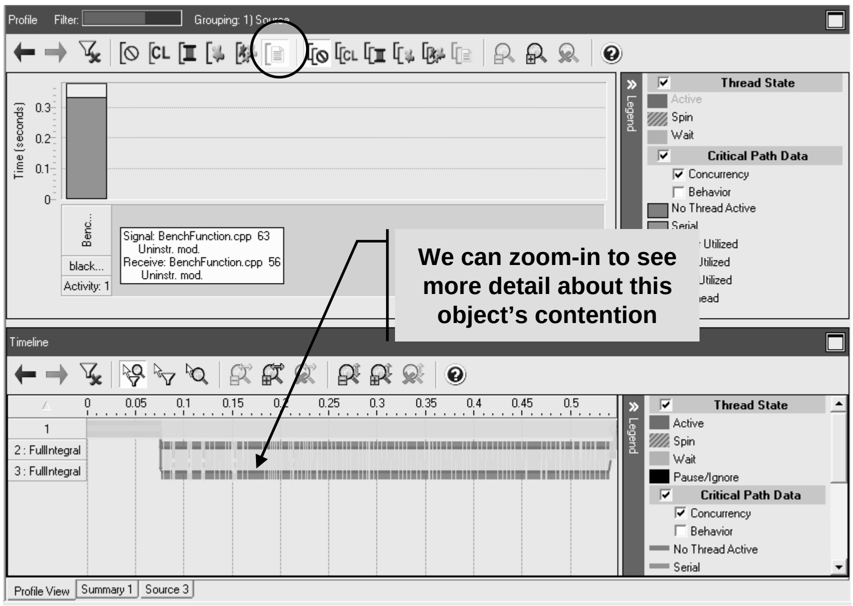
Zoom-in for more detail at any time



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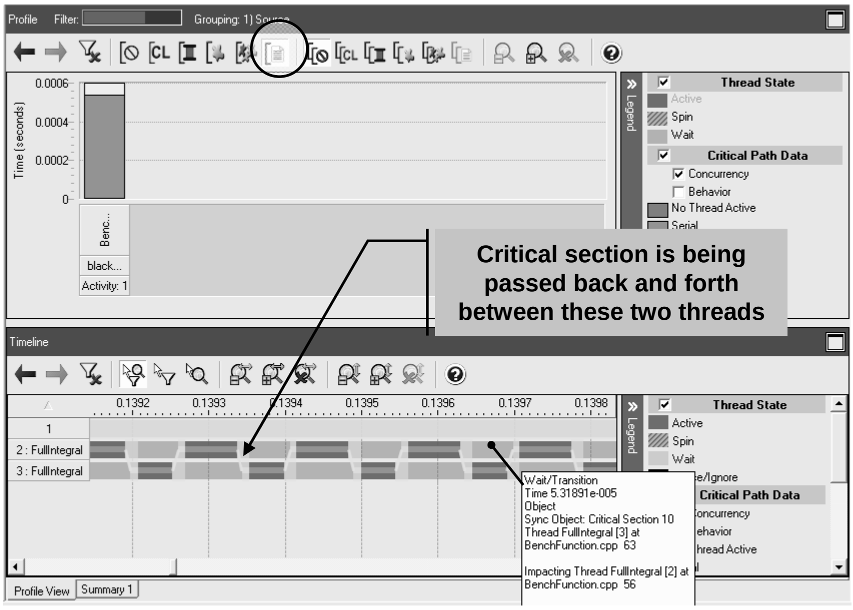
Critical Section is causing serialization



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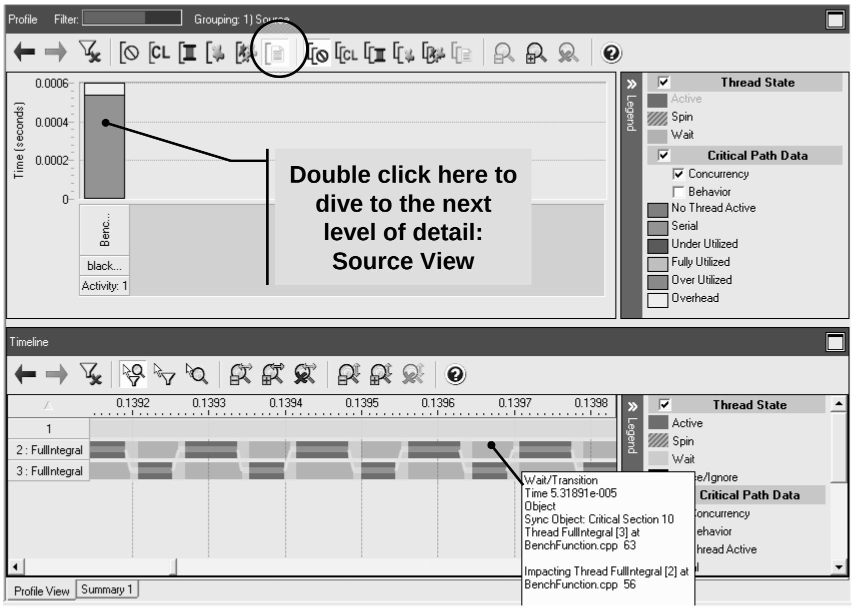
Dive for source view of this location



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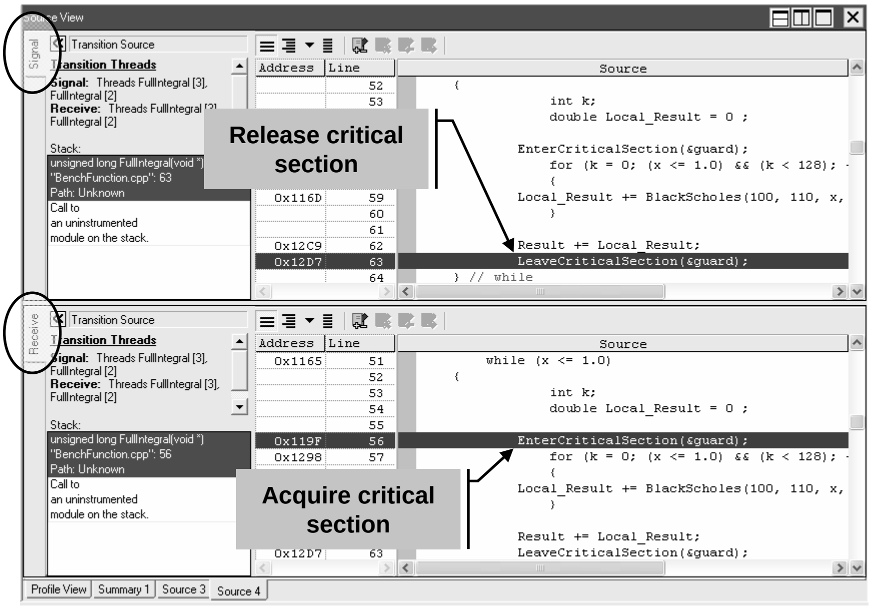
Synchronization source view



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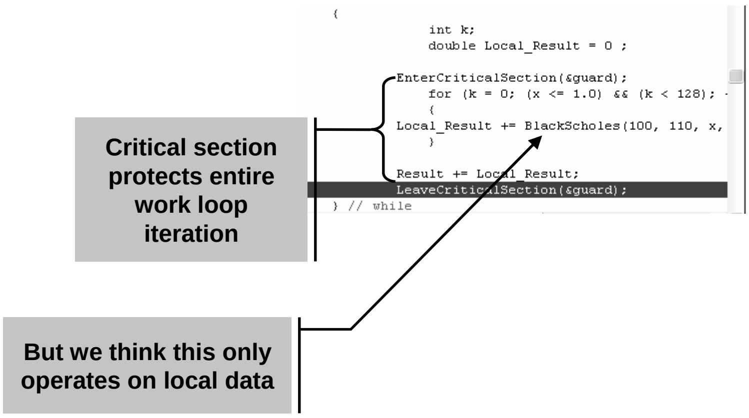
Analyze this critical section



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Optimize this critical section

```
{
        int k;
        double Local_Result = 0 ;

    EnterCriticalSection(&guard);
        for (k = 0; (x <= 1.0) && (k < 128); ·
        {
    Local_Result += BlackScholes(100, 110, x,
        }

    Result += Local_Result;
    LeaveCriticalSection(&guard);
} // while
```

Let's reduce the size of the critical section so it only protects the reduction variable

```
{
        int k;
        double Local_Result = 0 ;

        for (k = 0; (x <= 1.0) && (k < 128); ·
        {
    Local_Result += BlackScholes(100, 110, x,
        }
    EnterCriticalSection(&guard);
    Result += Local_Result;
    LeaveCriticalSection(&guard);
} // while
```

Verify the correctness of this assumption with Thread Checker

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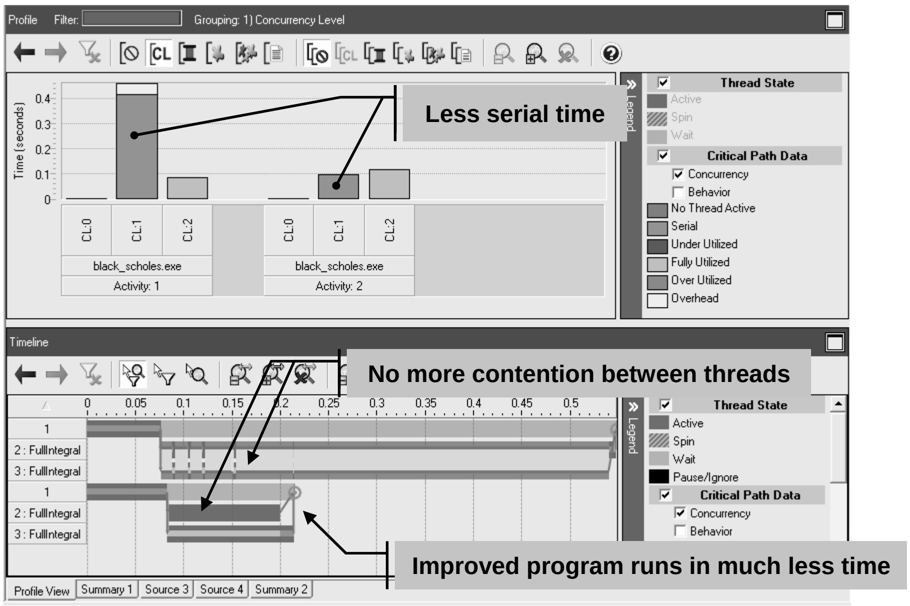
Compare results of new program run



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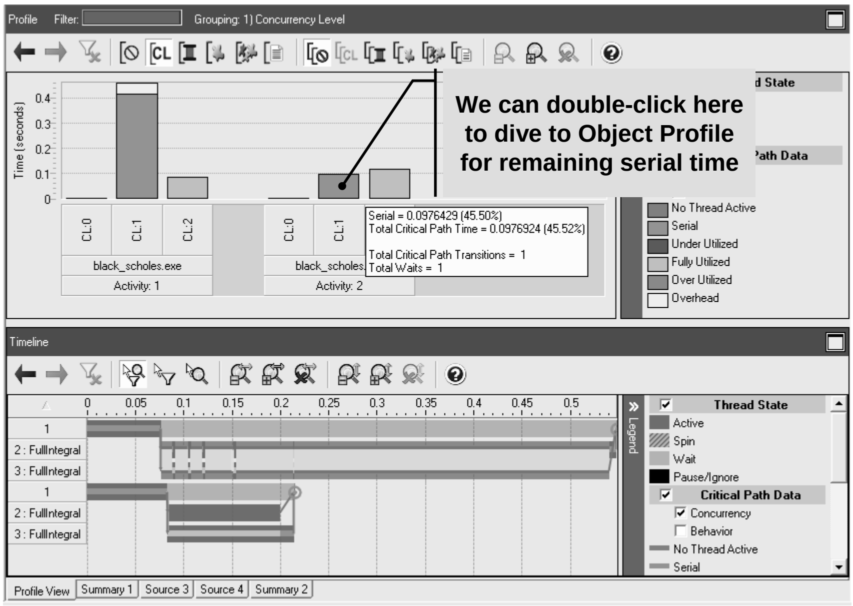
Dive to see what serial time is left



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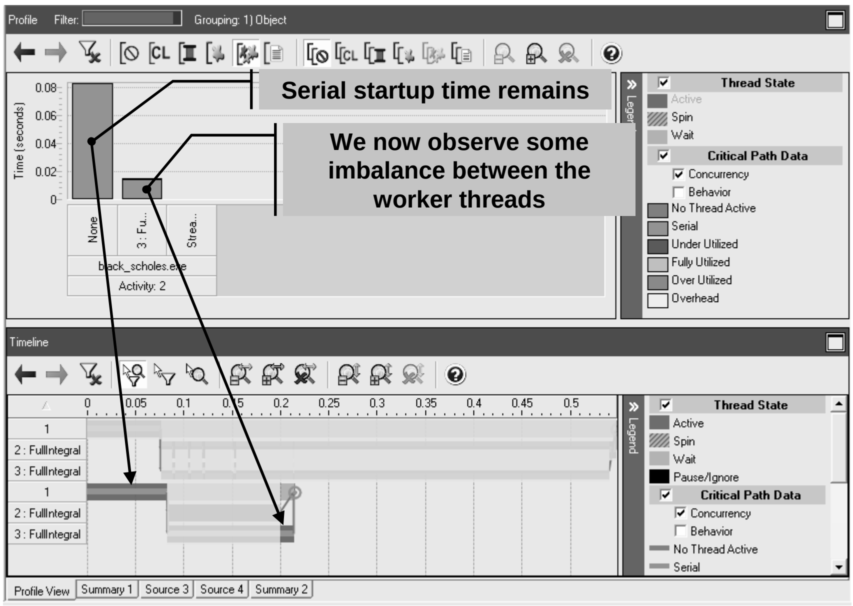
Object profile for serial time



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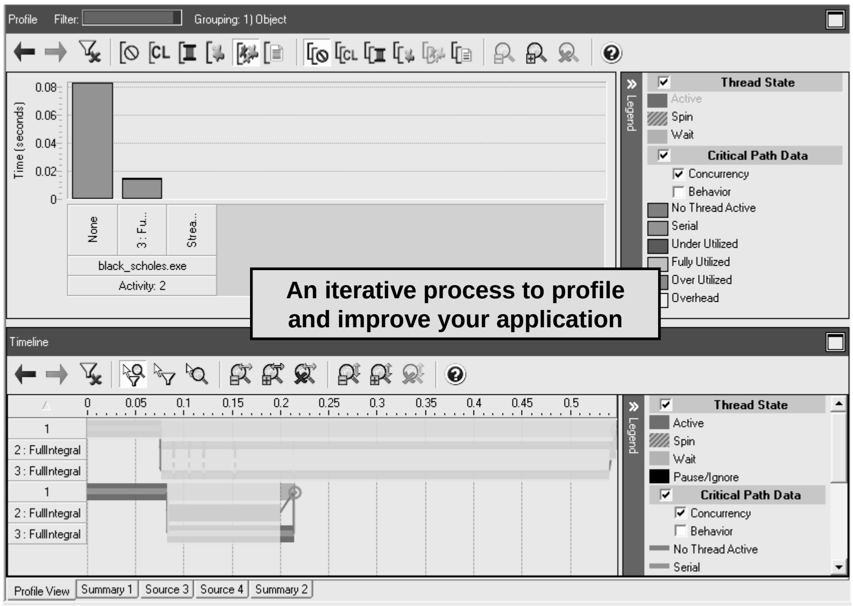
Iterative process



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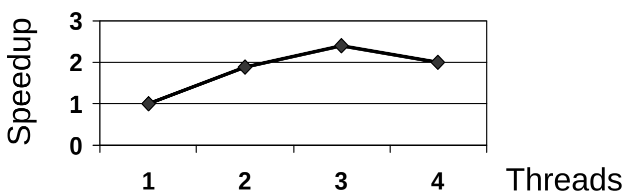
Different causes of poor scalability

A tool could help determine the actual cause



1. Insufficient parallel work
2. Synchronization overhead
3. Contention
4. Load imbalance
5. Task granularity
6. Memory bandwidth / false sharing
7. ...

Thread Profiler can help you detect many issues that limit scalability

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