Optimize an Existing Program by Introducing Parallelism

with Intel® Parallel Studio XE for Windows*

Introduction

This guide will help you add parallelism to your application using a powerful threading library included with Intel® Parallel Studio XE. You will get hands-on experience with sample code in a 15-minute exercise that will show you the power of Intel® Threading Building Blocks (Intel® TBB). You can then explore the Intel Parallel Studio XE components on your own by using the six-step process to add parallelism to your own application. The final section is packed with resources to help you in the process of threading.

With the parallel_for building block, in just a few lines of code you can increase performance by up to 1.59x (from one thread to two threads in the provided Adding_Parallelism sample code). Your results may be different so after completing this guide, try it on your code. Here is an example of a function before and after converting it from serial to parallel: Figure 1

Figure 1

```
    void change_array(){
    //Instructional example - serial version
        for (int i=0; i < list_count; i++){
            data[i] = busyfunc(data[i]);
        }
    }
```

```
    void parallel_change_array(){
    //Instructional example - parallel version
      parallel_for (blocked_range<int>(0,
      list_count),
        [=](const blocked_range<int>& r) {
           for (int i=r.begin(); i < r.end();
           i++){
              data[i] = busyfunc(data[i]);
              }
        });
    }
```

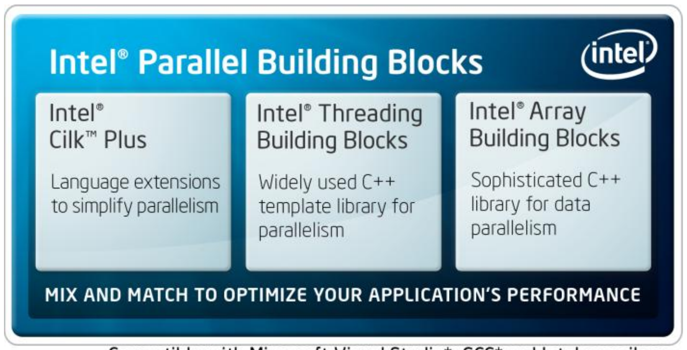
Intel Parallel Studio XE is a comprehensive tool suite that provides C++ and Fortran developers a simplified approach to building future proof, high-performance parallel applications for multicore processors.

Intel® Composer XE 2011 combines optimizing compilers, Intel® Parallel Building Blocks (Intel® PBB) and high-performance libraries

Intel® Inspector XE 2011 is a powerful thread and memory error checker

Static Security Analysis helps close security vulnerabilities and weed out a range of bugs

Intel® VTune™ Amplifier XE is an advanced performance profiler


Intel® Parallel Building Blocks
intel
Intel® Cilk™ Plus
Language extensions to simplify parallelism
Intel® Threading Building Blocks
Widely used C++ template library for parallelism
Intel® Array Building Blocks
Sophisticated C++ library for data parallelism
MIX AND MATCH TO OPTIMIZE YOUR APPLICATION'S PERFORMANCE

Compatible with Microsoft Visual Studio*, GCC* and Intel compilers
Supports multiple operating systems and platforms

Intel® Parallel Building Blocks (Intel® PBB) helps you take advantage of multicore processing power. It consists of three parallel programming approaches that simplify adding parallelism into your applications.

- Intel® Cilk™ Plus is an Intel® C/C++ Compiler-specific implementation of parallelism: Intel Cilk Plus is for C++ software developers who write simple loop and task parallel applications. It offers superior functionality by combining vectorization features with high-level loop-type data parallelism and tasking.
- Intel® Threading Building Blocks (Intel® TBB) is a C++ template library for general-purpose loop and task parallelism applications. It includes scalable memory allocation, load-balancing, work-stealing task scheduling, a thread-safe pipeline and concurrent containers, high-level parallel algorithms, and numerous synchronization primitives.
- Intel® Array Building Blocks provides a generalized vector parallel programming solution that frees application developers from dependencies on particular low-level parallelism mechanisms or hardware architectures. It is for software developers who write compute-intensive, vector parallel algorithms.

This evaluation guide will focus on Intel TBB.

Interactive Demonstration: The Power of Parallelism

Intel TBB is a set of "building blocks" for going parallel. It uses C++ templates to provide powerful parallel functionality that works with common programming patterns. For example, Intel TBB's parallel_for construct can be used to convert the work of a standard serial "for" loop into a parallel one. Parallel_for is the easiest and most commonly used building block in Intel TBB, so developers new to parallelism should start with it.

Why Intel® Threading Building Blocks—Portable, Reliable, Scalable, Simple

- Portability—Thread API works across 32-bit and 64-bit Windows*, Linux*, and Mac OS* X platforms and open-source versions of FreeBSD*, IA Solaris*, QNX, and Xbox* 360
- Open Design—Compiler, operating system, and processor independent
- Forward Scaling—Automatically scales to more cores as they become available without changing code or recompiling
- Comprehensive Solution—Includes primitives and threads, scalable memory allocation and tasking, parallel algorithms, and concurrent containers
- Licensing Options—Commercial and open-source versions are available. See below for links.
- Packaging—Available with Intel Parallel Studio, Intel® Parallel Studio XE, single package, and in open source

For more information, please visit: the commercial or the open source sites.

Try It Yourself

Here is a simple example using Intel TBB parallel_for. You can read it here or try it yourself using the steps below and the Adding_Parallelism sample code.

Step 1. Install and Set Up Intel® Parallel Studio XE

Estimated completion time: 15-30 minutes

1 Download an evaluation copy of Intel Parallel Studio XE.

2. Install Intel Parallel Studio XE by clicking on the **parallel_studio_xe_2011_setup.exe** (can take 15 to 30 minutes depending on your system).

Step 2. Install and View the Adding_Parallelism Sample Application

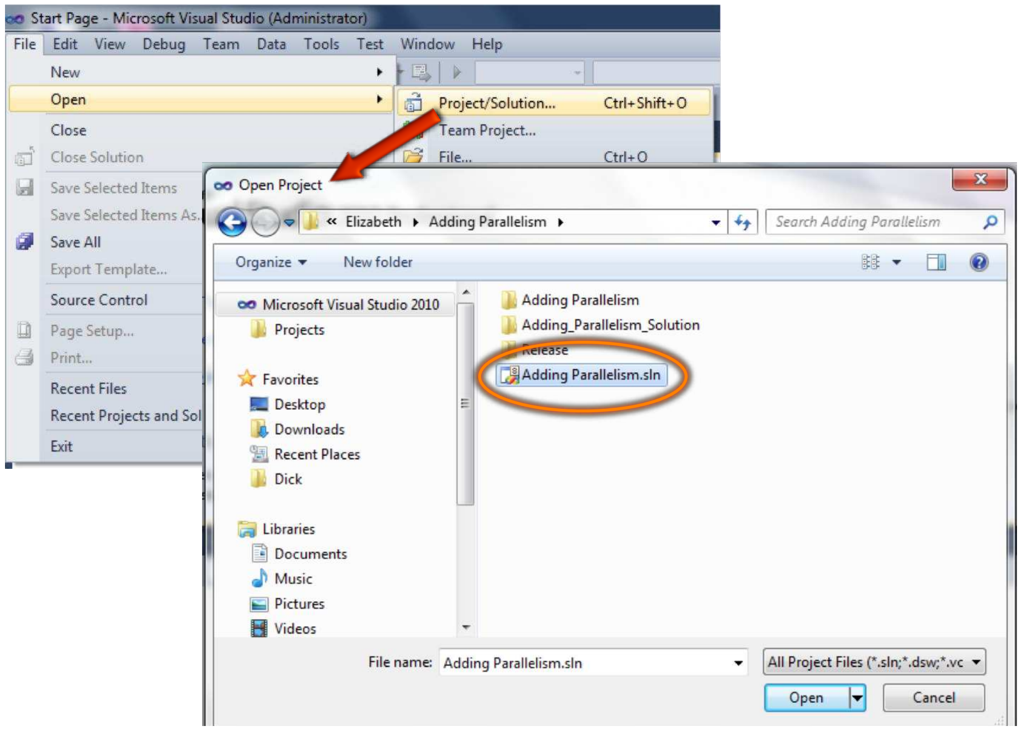
Install the sample application:

1. Download the Adding_Parallelism_Exercise.zip sample file to your local machine. This is a C++ console application created with Microsoft* Visual Studio* 2005.
2. Extract the files from the Adding_Parallelism_Exercise.zip file to a writable directory or share on your system, such as My Documents\Visual Studio 20xx\Intel\samples folder.

View the sample:

1. Load the solution into Microsoft Visual Studio by selecting File > Open > Project/Solution. Navigate to the Adding_Parallelism_Exercise.sln file in the directory that contains the .zip file you extracted it from: Figure 2

Figure 2



2. Notice this solution contains two projects. The first is the serial sample code and an Intel TBB example. The second, Adding_Parallelism_Solution, contains the serial sample code converted to use Intel TBB. Figure 3

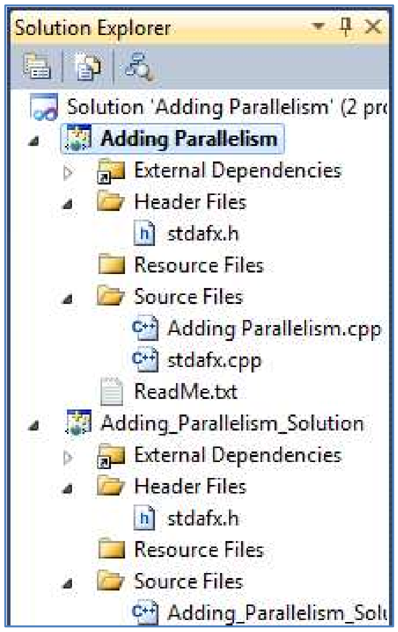
3. Both projects have been configured to use Intel® C++ Composer XE. You can confirm this setting by right clicking on the project name, choosing **Properties**, and navigating to General under Configuration Properties. Figure 4

4. View the code in Adding_Parallelism.cpp or read the following brief description.

   The sample code includes four instructional functions, all of which use for loops. The first two are change_array and its parallel version, parallel_change_array. This function and its parallel version are purely examples of how to use parallel_for; they are also shown in the introduction of this guide. The second two functions are both serial and find primes in an array of random numbers. The first version places a 1 into a companion array in the position of each prime it finds. The second version increments a counter when a prime is found and returns a value.

   This guide walks you through converting the first version of find_primes to be parallel. The second function is only slightly more complex to convert, and it is left as an optional exercise. The solution code is included in the sample for both functions.

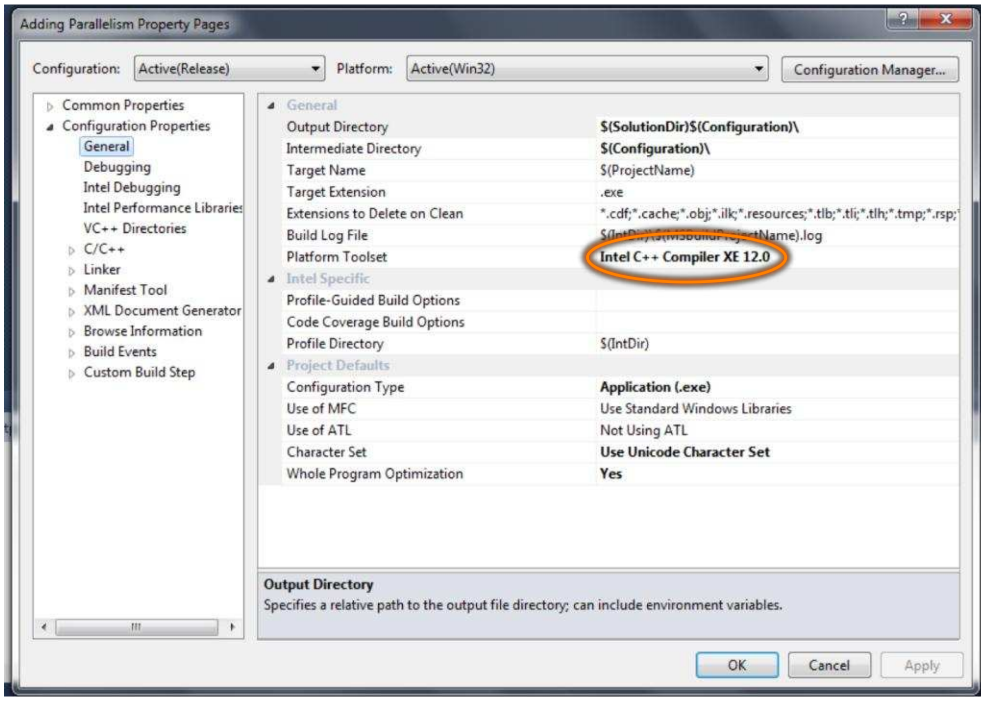
Figure 3



Solution Explorer

- Solution 'Adding Parallelism' (2 pr
  - Adding Parallelism
    - External Dependencies
    - Header Files
      - stdafx.h
    - Resource Files
    - Source Files
      - Adding Parallelism.cpp
      - stdafx.cpp
    - ReadMe.txt
  - Adding_Parallelism_Solution
    - External Dependencies
    - Header Files
      - stdafx.h
    - Resource Files
    - Source Files
      - Adding_Parallelism_Solu

Figure 4



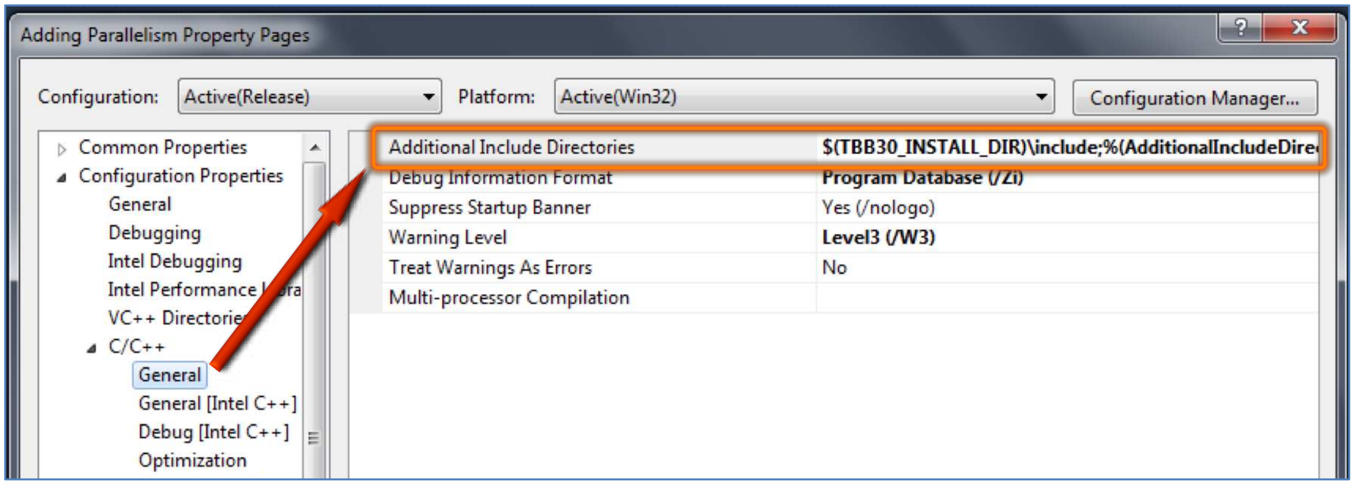
Configuration: Active(Release) Platform: Active(Win32) Configuration Manager...

General	
Output Directory	**$(SolutionDir)$(Configuration)**
Intermediate Directory	**$(Configuration)**
Target Name	$(ProjectName)
Target Extension	.exe
Extensions to Delete on Clean	*.cdf;*.cache;*.obj;*.ilk;*.resources;*.tlb;*.tli;*.tlh;*.tmp;*.rsp;
Build Log File	$(IntDir)\$(MSBuildProjectName).log
Platform Toolset	**Intel C++ Compiler XE 12.0**
Intel Specific	
Profile-Guided Build Options	
Code Coverage Build Options	
Profile Directory	$(IntDir)
Project Defaults	
Configuration Type	**Application (.exe)**
Use of MFC	Use Standard Windows Libraries
Use of ATL	Not Using ATL
Character Set	**Use Unicode Character Set**
Whole Program Optimization	**Yes**

Output Directory
Specifies a relative path to the output file directory; can include environment variables.

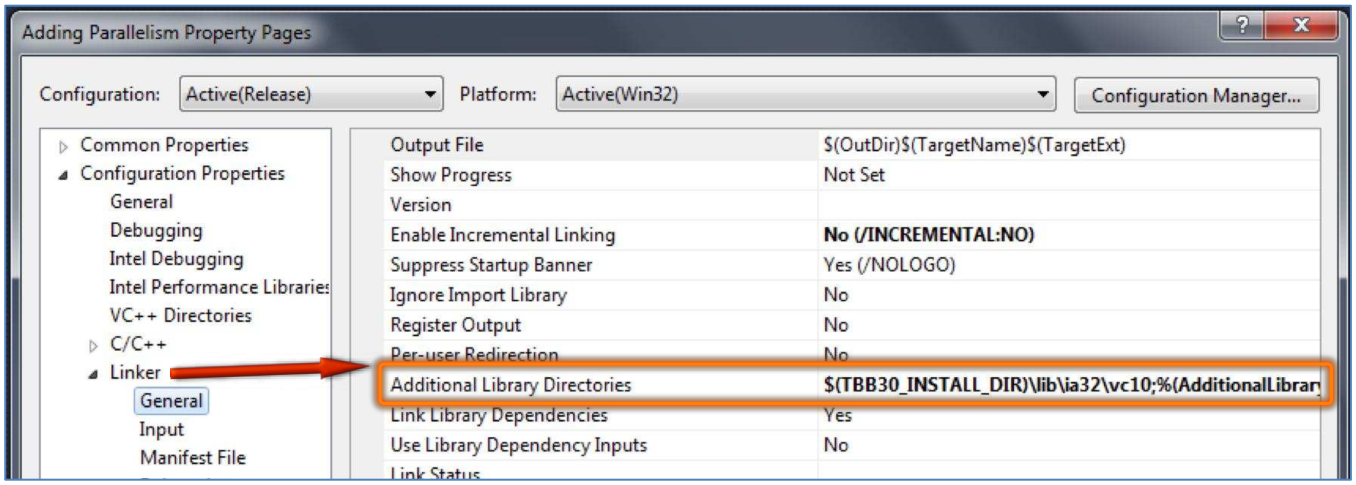
5. These projects have also been configured to use Intel TBB with support for lambda expressions. You can view the settings by right-clicking each project in the Solution Explorer pane and choosing Properties. The relevant changes are shown in Figure 5 and 6. See the comments at the top of Adding_Parallelism.cpp for additional information.

Figure 5



Additional Include Directories	$(TBB30_INSTALL_DIR)\include;%(AdditionalIncludeDire
Debug Information Format	Program Database (/Zi)
Suppress Startup Banner	Yes (/nologo)
Warning Level	Level3 (/W3)
Treat Warnings As Errors	No
Multi-processor Compilation	

Figure 6



Output File	$(OutDir)$(TargetName)$(TargetExt)
Show Progress	Not Set
Version	
Enable Incremental Linking	No (/INCREMENTAL:NO)
Suppress Startup Banner	Yes (/NOLOGO)
Ignore Import Library	No
Register Output	No
Per-user Redirection	No
Additional Library Directories	$(TBB30_INSTALL_DIR)\lib\ia32\vc10;%(AdditionalLibrar
Link Library Dependencies	Yes
Use Library Dependency Inputs	No
Link Status	

Step 3. Convert the find_primes Function Using Intel TBB parallel_for

1. Notice that the proper includes have been added to the code already. To use Intel TBB parallel_for, you must include "tbb/parallel_for.h" and "tbb/blocked_range.h."
2. Begin by making a copy of the find_primes function and renaming it "parallel_find_primes." No changes need to be made to the function's return type or parameter list. Here is the original (serial) find_primes function: Figure 7
3. Inside parallel_find_primes, call parallel_for. You can model this call on the one in the parallel_ change_array function, or you can use the code provided here or in the Adding_Parallelism_ Solution project. Parallel_for takes the work of a serial for loop (which you specify) and distributes it to multiple threads to execute in parallel. Parallel_for takes two parameters, which are described in steps 4 and 5. Here is the parallel_find_primes function so far: Figure 8

Figure 7

```
void find_primes(int* &my_array, int
*&prime_array){
   int prime, factor, limit;
   for (int list=0; list < list_count;
   list++){
    prime = 1;
    if ((my_array[list] % 2) ==1) {
      limit = (int)
      sqrt((float)my_array[list]) + 1;
      factor = 3;
      while (prime && (factor <=limit)) {
         if (my_array[list] % factor == 0)
         prime = 0;
         factor += 2;
      }
    } else prime = 0;
    if (prime) {
      prime_array[list] = 1;
    }
    else
      prime_array[list] = 0;
   }
}
```

Figure 8

```
void parallel_find_primes(int *&my_array,
int *& prime_array){
    parallel_for (
```

How does parallel_for work?

Parallel_for is the easiest and most commonly used template in Intel TBB. It takes the work of a serial for loop, breaks it into tasks, and then distributes those tasks to all available processing cores at run-time. Using parallel_for allows you to think in terms of the work needing to get done, not about threading details. You only need to ensure that the iterations of your serial for loop are independent—if they are, you can use parallel_for.

Intel TBB manages the creation, deletion, and load balancing of threads using a thread pool that is sized appropriately for the number of processing cores available. Tasks are then distributed to the threads. This usage model helps reduce overhead and ensure future- proof scalability. By default, Intel TBB will create a thread pool to maximize the computing resources available.

Although the parallel_for samples in this guide use default options, there are many tunable parameters developers can use to get the best performance for their application. These examples also show the lambda expression form, but another form exists for use with compilers that do not support the C++0x standard.

4. Pass a blocked_range as the first parameter. Blocked_range is a type included in Intel TBB that is used to specify the range of a for loop. When calling parallel_for, the blocked_range will have the same bounds as the original serial loop (0 to list_count in this example). The parallel_for implementation will create many tasks, each operating over a portion of the total range you specify. The Intel TBB scheduler will assign each of these tasks its own smaller blocked_range. Here is the parallel_find_primes function so far: Figure 9

Figure 9

```
void parallel_find_primes(int *&my_array,
int *& prime_array){
    parallel_for (blocked_range<int>(0,
    list_count),
```

5. Write the body of the for loop as a lambda expression and pass it as the second parameter. With this parameter, you are specifying the work for each task. Since the for loop will now be executed in chunks by tasks, you will need to modify your original for loop bounds to be the range assigned to each task (<range>.begin() and <range>.end()).

   You will also need to define the work of each task by writing the original for loop body as a lambda expression. A lambda expression allows the compiler to do the work of creating a function object that can be used with Intel TBB template functions. A lambda expression is a function specified on-the-fly in code, similar in concept to lambda functions in lisp or to anonymous functions in .NET languages.

   In the code on this page, the [=] introduces the lambda expression. Using "[=]" instead of "[&]" specifies that the variables list_count and my_array, which are declared outside the lambda expression, should be "captured" *by value* as fields inside the function object. After the [=] is the parameter list and definition for the operator() of the generated function object. Here is the complete parallel_find_primes function: Figure 10

Figure 10

```
    void parallel_find_primes(int *&my_array,
    int *& prime_array){
      parallel_for (blocked_range<int>(0,
      list_count),
        [=](const blocked_range<int>& r) {
          int prime, factor, limit;
          for (int list=r.begin(); list <
          r.end(); list++){
             prime = 1;
             if ((my_array[list] % 2) ==1) {
               limit = (int)
               sqrt((float)my_array[list]) +
               1;
               factor = 3;
               while (prime && (factor
               <=limit)) {
                  if (my_array[list] % factor
                  == 0) prime = 0;
                    factor += 2;
               }
             }
             else prime = 0;
          if (prime)
             prime_array[list] = 1;
          else
             prime_array[list] = 0;
          }
      });
    }
```

6. Modify the main function to call the parallel_find_primes function and time it. The main code provided calls find_primes and times it using the Intel TBB tick_count object. Tick_count is a thread-safe and thread-aware timer. Here is the code to time and call parallel_find_primes. No other code is needed in main to use Intel TBB. Figure 11

Figure 11

```
    tick_count
    parallel_prime_start=tick_count::now();
    parallel_find_primes(data, isprime);
    tick_count
    parallel_prime_end=tick_count::now();
    cout << "Time to find primes in parallel
    for " << list_count << " numbers: " <<
    (parallel_prime_end -
    parallel_prime_start).seconds()
    << " seconds." << endl;
```

Step 4. Build the Parallel Version and Verify Speedup

1. Build the solution using Build >Build Solution. Figure 12
2. Run the application from within Microsoft Visual Studio with **Debug > Start Without Debugging**. Figure 13

Figure 12

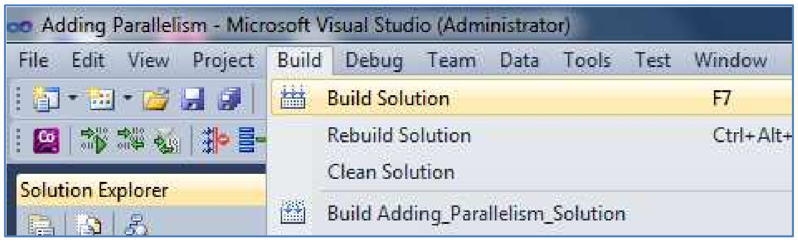
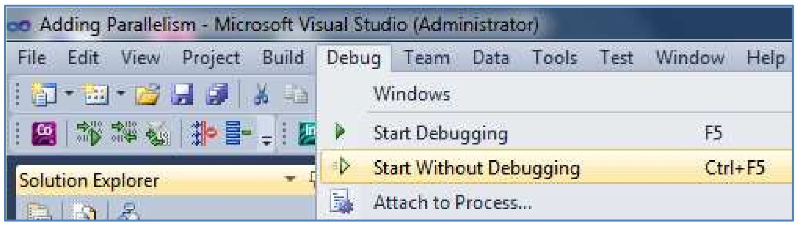
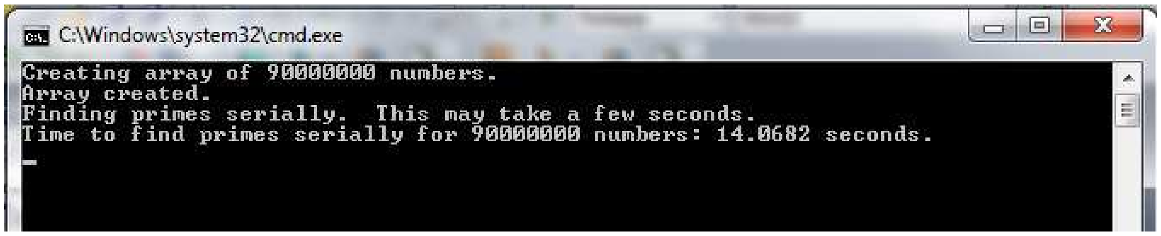

Adding Parallelism - Microsoft Visual Studio (Administrator)
File Edit View Project Build Debug Team Data Tools Test Window
Build Solution F7
Rebuild Solution Ctrl+Alt+
Clean Solution
Solution Explorer
Build Adding_Parallelism_Solution

Figure 13


Adding Parallelism - Microsoft Visual Studio (Administrator)
File Edit View Project Build Debug Team Data Tools Test Window Help
Windows
Start Debugging F5
Start Without Debugging Ctrl+F5
Solution Explorer
Attach to Process...

3. Assuming you are running on a multicore system, you should see significant speedup. For the most accurate timings, measure serial and parallel time in separate runs. Figure 14 (serial) and 15 (parallel)

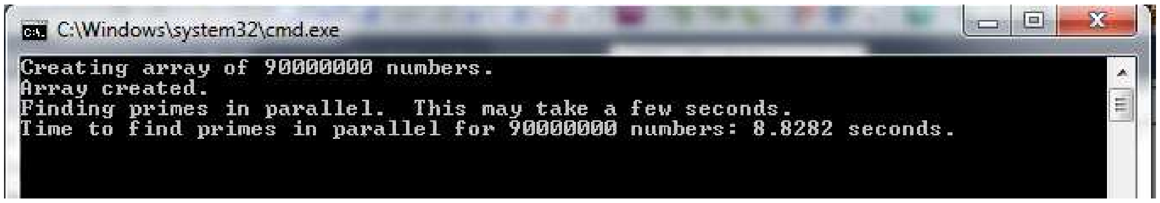
Figure 14 – Serial Execution Time = 14.07 secs



C:\Windows\system32\cmd.exe

```
Creating array of 90000000 numbers.
Array created.
Finding primes serially.  This may take a few seconds.
Time to find primes serially for 90000000 numbers: 14.0682 seconds.
_
```

Figure 15 – Parallel Execution Time = 8.83 secs



C:\Windows\system32\cmd.exe

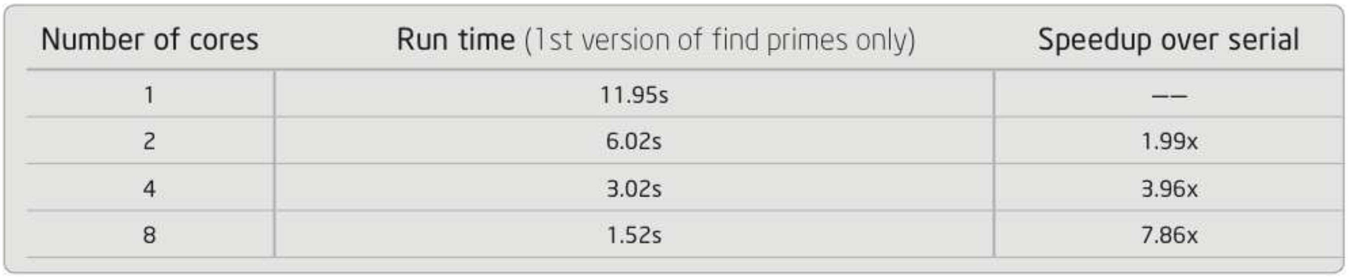
```
Creating array of 90000000 numbers.
Array created.
Finding primes in parallel.  This may take a few seconds.
Time to find primes in parallel for 90000000 numbers: 8.8282 seconds.
```

Success

This example demonstrates how easily parallel_for can be applied to a conforming for loop and how it can deliver a significant performance increase even without further tuning. While the scalability attained in this example is nearly perfect, in general the speedup achieved by parallel_for will depend on the algorithm and data structure being used. In many cases, tuning using Intel® VTune™ Amplifier XE can improve scalability even further.

Speedup for this example, using a dual-socket Intel® Core™ i7 laptop (1.6 GHz, 4 cores processor with 4 GB RAM) and Microsoft Windows* 7, Intel Parallel Studio XE update 1, Microsoft Visual Studio 2010 with 90,000,000 numbers: Figure 16

Figure 16



Number of cores	Run time (1st version of find primes only)	Speedup over serial
1	11.95s	——
2	6.02s	1.99x
4	3.02s	3.96x
8	1.52s	7.86x

What Now? Six Steps to Achieving Parallelism with Your Own Code

Parallelism has the potential to significantly increase the performance and expand the possibilities of many compute-intensive applications. However, threading commercial software is never as simplistic as an instructional sample. The components of Intel Parallel Studio XE are designed to reduce the complexity of threading, debugging, and tuning real-world applications. To apply parallel_for to your own code, first determine where to use it. The process below will help you to get started.

1. Identify hotspots.	Run hotspots analysis in Intel® VTune™ Amplifier XE to see which functions in your application take the most time.
2. Drill into code looking for a compute-intensive for loop.	Double-click the hottest functions to see the code and search for key loops.
3. Find and isolate dependencies in a chosen loop.	Trace through at least three iterations of the loop in reverse order. If it works, there are most likely no loop-carried data dependencies.
4. Convert to Intel® TBB parallel_for.	Change the outermost loop (if nested) and convert to parallel_for (with a lambda expression, if possible).
5. Verify correctness using Intel® Parallel Inspector.	Run threading errors analysis in Intel Inspector XE to verify your parallel code has no data races.
6. Measure increased performance.	Compare serial to parallel runs to compute speedup from parallelization.

What if the code I need to optimize isn't appropriate for parallel_for?

If your code doesn't feature compute- intensive for loops, Intel® TBB provides many other options for steps 2, 3, and 4 in the process at left. The Adding_Parallelism code sample also includes an optional function that can be converted to parallel_reduce. Parallel_reduce is

a template similar to parallel_for, but it allows a value (such as a min, max, total, or found index) to be returned from the loop. Intel TBB also supports more complex algorithms like sorting, pipelining, and recursion.

The Path to Parallelism

Key Concept

Choosing Small, Representative Data Sets - We are here to help developers write correct, high-performing code that will take advantage of both today's and tomorrow's processing power. Learn more from Intel experts about parallelism, Intel® Parallel Studio, and other related subjects.

Additional Resources

theadingbuildingblocks.org – Intel TBB open source web site.

Learning Lab – Technical videos, whitepapers, webinar replays and more

Intel Parallel Studio XE product page – How to videos, getting started guides, documentation, product details, support and more

Evaluation Guide Portal – Additional evaluation guides that show how to use various powerful capabilities.

Download a free 30 day evaluation

Optimization Notice