Converting Parallel Code From Low-Level Abstractions to Higher-Level Abstractions

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Libraries Make Parallel Programming Easier

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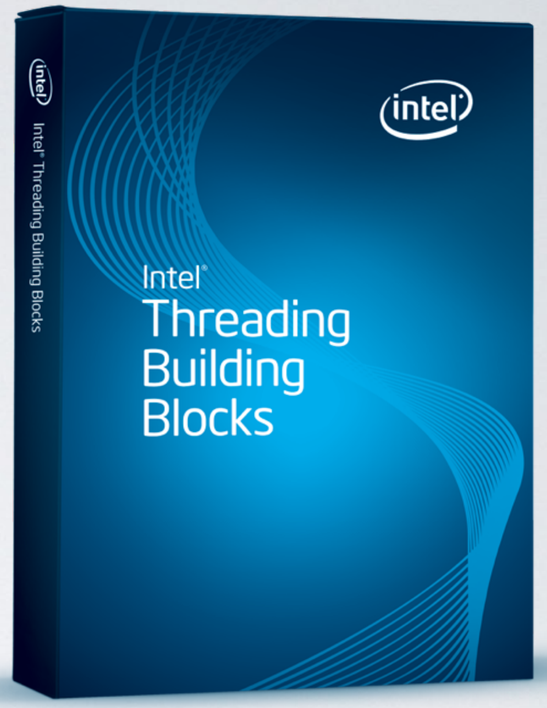
OpenMP™

Libraries Make Parallel Programming Easier



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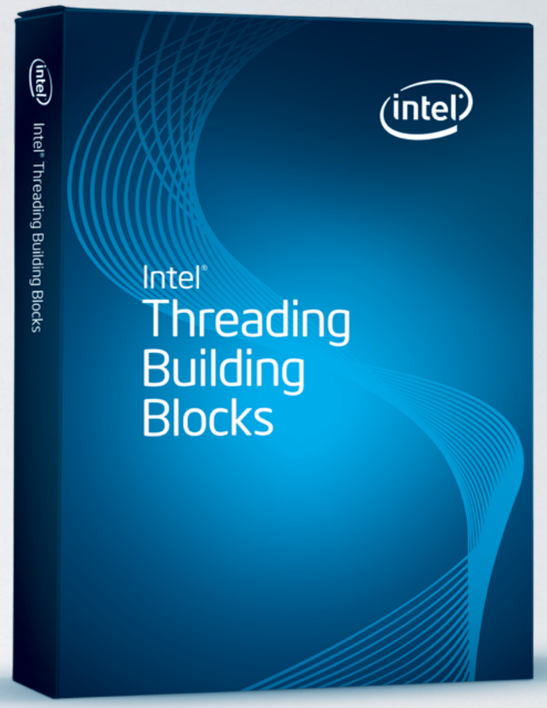

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java.util.concurrent

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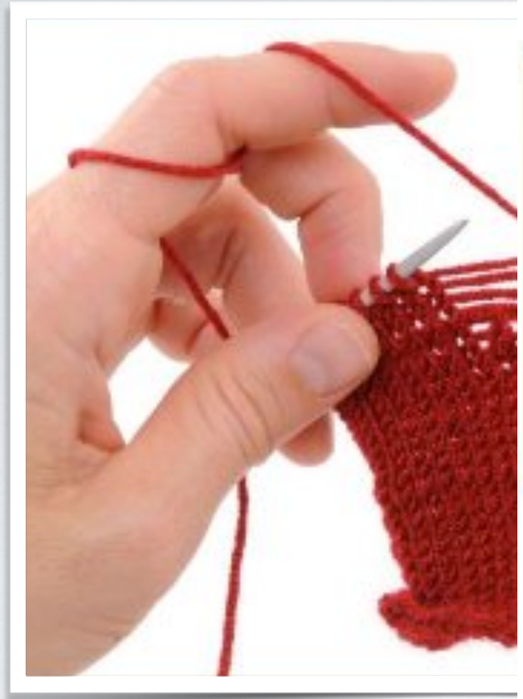

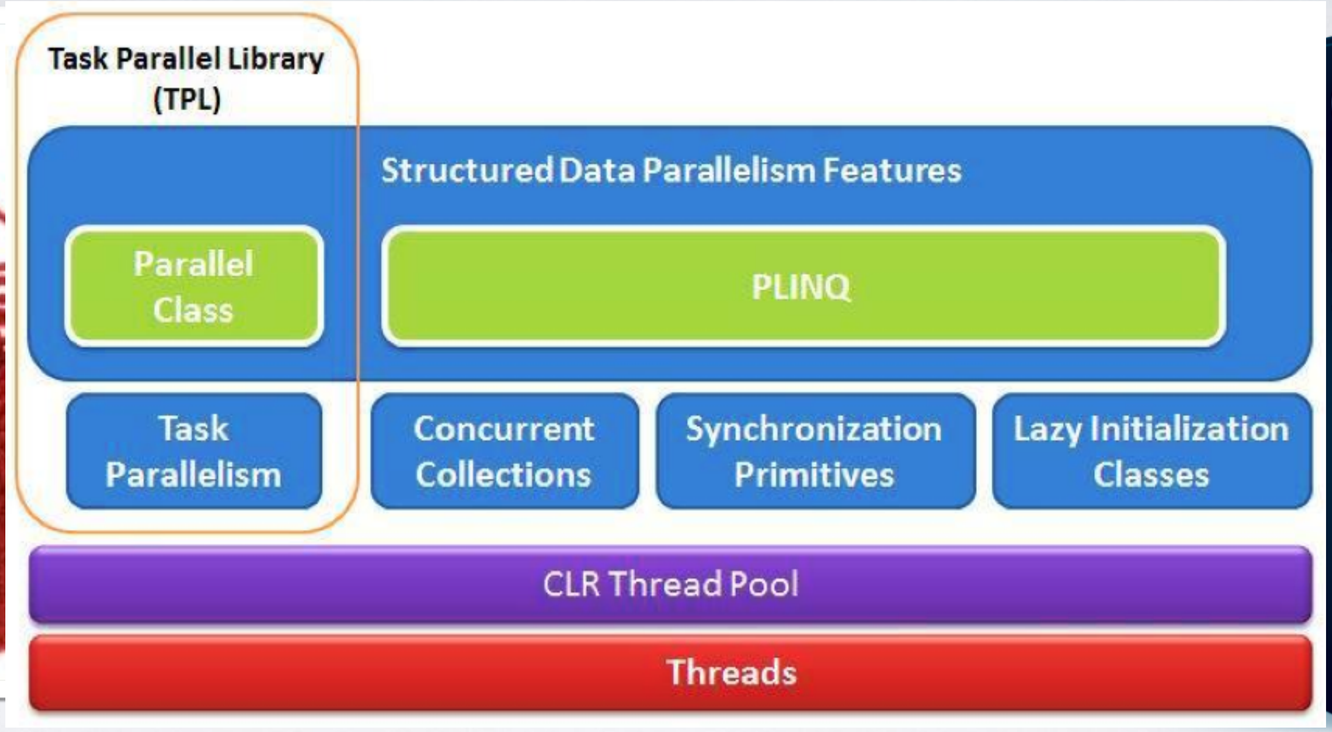

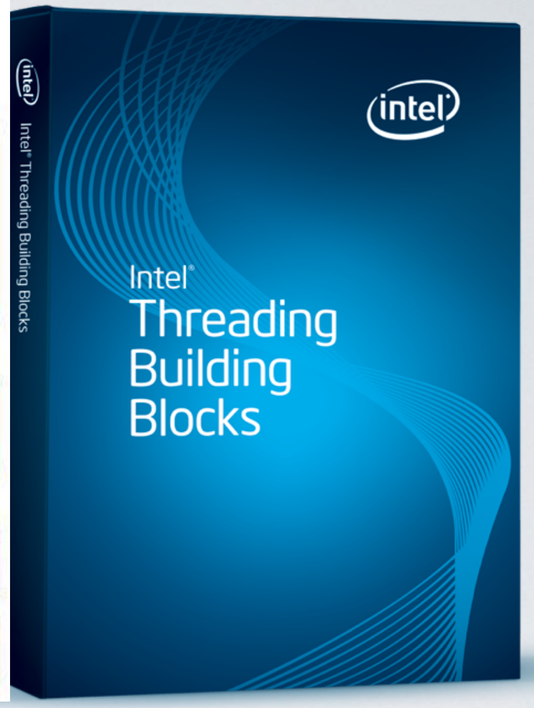

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Developers Still Use Old Libraries

Two recent empirical studies for C# and Java [1,2]

- Thread is still the primary choice for most developers.

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- Thread is still the primary choice for most developers.

Disadvantages of using old libraries:

- Threads are heavyweight, less scalable, more code bloat
- New platforms no longer support Thread

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Developers Need Tool Support For Migration

Millions SLOC use old parallel libraries and need migration

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We provide two refactorings for C#

Example - Thread (Since 2003)

```
Thread thread = new Thread(foo);
thread.Priority = ThreadPriority.BelowNormal;
thread.Start(arg);
thread.Join();
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+ Represents an actual OS-level thread, highest degree of control (stack size, priority, etc.)

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- Developers need to manage the thread life cycle

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- No simple ‘joining’ or ‘waiting’ operation

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Preferred way to write multithreaded code

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Built a static analysis tool with Microsoft's Roslyn
a set of open-source compilers and code analysis APIs for C# and VB
roslyn.codeplex.com

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96 apps use Thread, ThreadPool, and task at the same time

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Contacted the top 10 users for the tags "multithreading" and "C#"

We asked them some interesting questions about parallel abstractions

in the paper

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Workflow

(1) Taskifier identifies Thread or ThreadPool instances
(2) Converts the member accesses and method calls to the corresponding ones
(3) Optimizes the new code for special cases

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32% of existing tasks have at least one I/O blocking operation and 9% use Thread.Sleep(>1 second).

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1- I/O and CPU-bound

(i) Checks the members of the Stream if there is any …Async method (naming convention)

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thread.Start(foo);
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public static void foo()
{
  ...
  var str = stream.Read();
  ...
}
```

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Task.Run(()=> foo());
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```
Thread.Sleep => await Task.Delay
```

(3) Special Cases

1- Understanding the shape of the computation (I/O and CPU-bound)

2- Behavior difference in exception handling

An unhandled exception in Thread and ThreadPool abstractions results in termination of the applications.

An unhandled exception in Task is propagated back to the joining thread when it is waited.

Naive migration from Thread to Task can make the unhanded exceptions silenced

(3) Special Cases

1- Understanding the shape of the computation (I/O and CPU-bound)

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```
Task.Run(()=> foo()).FailFastOnException();

public static Task FailFastOnException(this Task task) {
    task.ContinueWith(c => Environment.FailFast("Task faulted",
c.Exception), TaskContinuationOptions.OnlyOnFaulted |
TaskContinuationOptions.ExecuteSynchronously |
TaskContinuationOptions.DetachedFromParent);
    return task;
}
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3- Foreground and Background is

in the paper

Developers Still Miss Opportunities

Tasks affords more flexibility and control but developers do not use the extra flexibility in most cases

Parallel Class (2010)

Support parallel programming design patterns

- Parallel.For/ForEach: data parallelism
- Parallel.Invoke: fork-join task parallelism

```
Parallel.For(0, n, (i)=> foo(i));

Parallel.Invoke( ()=> foo(arg1),
                 ()=> foo(arg2));
```

Developers Are Not Aware Of Parallel

From Formative Study

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Are you aware of Parallel class?

"Is this in .NET framework? It is the most elegant way of a parallel loop"

Simplifier

Refactoring tool that converts multiple Task instances to one of three Parallel operations.

Fork-join Tasks => Parallel.Invoke

Data parallelism => Parallel.For / ForEach

Simplifier suggests code snippets that can be transformed to Parallel operations

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Task[] tasks = new Task[n];
for(int i=0; i<n; i++)
{
    int temp = i;
    tasks[i] = new Task(
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Task.WaitAll(tasks);
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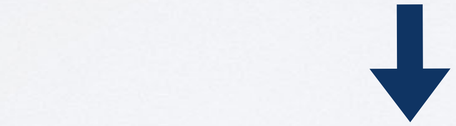

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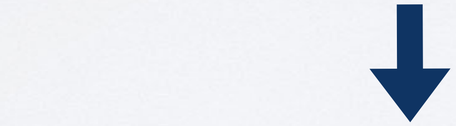

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Algorithm (Parallel.For)

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3) The iterator should be ‘++’ or ‘+=1’

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4) Analyze the statements inside the loop. Allowed statements:

- Task creation, task starting
- Adding task to the array
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- Task creation, task starting
- Adding task to the array
- Creating a temporary variable (Loop-carried dependence analysis)

```
Task[] tasks = new Task[n];
…
for(int i=0; i<n; i++)
{
    int temp = i;
    tasks[i] = new Task(
                    ()=> Queues[temp].Stop());
    tasks[i].Start();
}
…
Task.WaitAll(tasks);
```

Empirical Evaluation

Used the same code corpus from the Formative Empirical Study: 880 C# apps, 42M SLOC

Research Questions

(1) Are the refactorings applicable?

(2) Do the refactorings reduce the code bloat?

(3) Are the refactorings useful?

in the paper

(4) How much programmer effort is saved by the tools?

(5) Are the automated transformations safe?

(1) Our Tools Are Applicable

Taskifier

Taskifier migrated 78% of 1782 Thread instances.

Taskifier migrated all of 1244 ThreadPool instances to Task

Simplifier

Refactored all of 85 Task-based fork-join patterns to Parallel.Invoke

Refactored 92% of Task-based data-parallelism patterns to Parallel.For/ForEach

(2) Our Tools Reduce The Code Bloat

Taskifier

It is mostly one-to-one transformation

Achieved on average a 16% reduction in SLOC of the instance

Simplifier

Transforms multiple Task operations and helper operations to one equivalent method in the Parallel class

Achieved on average a 44% reduction for Parallel.Invoke

Achieved on average a 62% reduction for Parallel.For(Each)

(3) Our Transformations Are Useful

Chose 10 most recently updated apps for each Taskifier and Simplifier
Applied the tools ourselves and offered patches.
15 of 20 apps responded and accepted 53 patches.

Migration to Task is on their TODO list but they always postponed it because of working on new features.

Developers are looking forward to using our toolkit.

Conclusions

Describe the novel problem of migrating low-level parallel abstractions into their high-level counterparts

A toolkit inspired by our empirical study:

Taskifier migrates Thread(Pool) to Task in a fast & safe way

Simplifier finds parallel patterns and replace them with Parallel class

Evaluation:

highly applicable, useful,
saves programmer effort,
safer than manual migration
reduce the code bloat (62% on average for Parallel.For)