An Evaluation of the X10 Programming Language

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An Evaluation of the X10 Programming Language

A Writing Project
Presented to
The Faculty of the Department of Computer Science
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Masters of Science

By
Xiu Guo
Fall 2012
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Abstract

As predicted by Moore's law, the number of transistors on a chip has been doubled approximately every two years. As miraculous as it sounds, for many years, the extra transistors have massively benefited the whole computer industry, by using the extra transistors to increase CPU clock speed, thus boosting performance.

However, due to heat wall and power constraints, the clock speed cannot be increased limitlessly. Hardware vendors now have to take another path other than increasing clock speed, which is to utilize the transistors to increase the number of processor cores on each chip.

This hardware structural change presents inevitable challenges to software structure, where single thread targeted software will not benefit from newer chips or may even suffer from lower clock speed.

The two fundamental challenges are:

1. How to deal with the stagnation of single core clock speed and cache memory.
2. How to utilize the additional power generated from more cores on a chip.

Most software programming languages nowadays have distributed computing support, such as C and Java [1]. Meanwhile, some new programming languages were invented from scratch just to take advantage of the more distributed hardware structures. The X10 Programming Language is one of them.

The goal of this project is to evaluate X10 in terms of performance, programmability and tool support.
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1. Introduction

1.1 What is X10?
X10 is an open-source programming language developed to address the architectural challenge of multiple cores, hardware accelerators, clusters, and supercomputers by providing scalable performance in a productive manner. It is being developed by IBM Research, which roots X10 on a type-safe, class-based, object-oriented foundation.

The philosophy behind the new programming language, X10, is to make parallel programming easier to code and less-prone to deadlock and race condition. To achieve that, X10 embraces three principles: asynchrony, locality and atomicity [2]. Most of the other major programming languages now achieve their parallelism goal by adding additional libraries and APIs. However, because X10 was built from ground up with parallelism in mind, its native mode is to support asynchrony, locality and atomicity. Therefore, X10 might become a more effective alternative on distributed-computing due to its clearer goal. Its legitimacy as a useful alternative needs extensive experiments and evaluations.

1.2 Project Goal
The project will focus on whether X10 can utilize the divide-and-conquer concept well enough to serve as a pragmatic solution to parallelize certain algorithms and determine whether X10 is programmer-friendly enough to ease the difficulty when developing distributed software.

The performance evaluation will be based on a three-step process:
1. The collection of different divide-and-conquer problems.
2. Their implementation using Java threads and X10 (Java back-end) separately.

From the results above, one can draw a conclusion on whether X10 can offer a speedup in divide-and-conquer problems over Java or at least ease the difficulty of programming parallel programs with little or no performance lost.

With quantitative evaluation results, this project can serve as a guide for developers on finding an optimal approach in terms of a balance of performance and ease of programmability.
2. Algorithms and Platforms

2.1 Divide-and-conquer algorithms
Divide-and-conquer algorithms are widely known and used to speed up computation by reducing a complex problem into a collection of smaller sub-problems in a recursive fashion. By combining results from sub-problems, the outcome of the original master problem can be produced. [3]

2.2 Why divide-and-conquer algorithms
Because of the nature of divide-and-conquer algorithms, they are well suited for running in parallel. When a problem is divided into smaller sub-problems, each sub-problem can be assigned to a single thread which will send the result back to the main thread upon completion.

Evaluating the use of divide-and-conquer algorithms can lead to a better understanding of the efficiency to spawn threads, the ability to prevent race condition and deadlock, and the cost involved due to overhead.

2.3 Parallel Processing Platforms
In reality, the hardware available and the algorithm used are usually restricted by financial and research resources. A better execution language platform sometimes will noticeably boost productivity even when the above resources stay the same. It is the exact goal of this project to find out whether X10 is a better execution platform. However, first, the comparison language platform needs to be described.

2.3.1 Java Virtual Machine Threading Models
Java is known as platform-independent; however, it is somehow platform-dependent if the Virtual Machine performance is taken into consideration. Although Java's operations are consistent to users among different platforms, the underlying platforms usually handle
the implementation differently, especially for features like concurrency and multi-threading. For scheduling multiple threads, Java utilizes two models: cooperative and preemptive threading.

For the cooperative threading model, threads can decide whether to give up their processor resources to other queued threads. This model is safe and easy to use for programmers. A programmer can access variables without having to worry about them changing between lines of code. However, performance of this model relies highly on how well written the code is. Poorly written code may have certain threads occupy some processor resources all the time which starve other threads.

For the preemptive threading model, threads run independently from each other. Only one thread at a time has focus, but focus can change from one line of code to the next. The switching between threads is under the control of the operating system [4]. This model is considered a better approach because no threads can monopolize the CPU resources. On the other hand, this model sometimes introduces unnecessary switches by the operating system, which is out of the programmer's control. That creates a nondeterministic environment where the programmer has no knowledge beforehand of which scheduling the threads will follow.

While both models have their pros and cons, it is generally a good idea to adapt to both models when designing a Java multi-thread program.

2.3.2 X10 Performance Model
X10 is an object-oriented language designed specifically to enable the productive programming of multi-core and multi-node computers. In addition to the expected core language features of any modern object-oriented language, it contains additional constructs of expressing fine grained concurrency and distributed computation. [5]
The design of X10's syntax has significant overlap with Java's type system, though differences do exist. For example, instead of using “int i” for declaring an integer in Java, X10 uses “i:Int”. In X10, variables are declared using either the keyword “val” or “var”. “val” is similar to a constant in Java, but it does not need to have a value when declared. It only has to be assigned some value at some point. Once it has a value, the value cannot be changed. “var” is like a normal variable where the values it holds are updated as needed.

These are examples that show the differences but do not indicate any performance consideration in the design of the language. Researchers of X10 did put significant thought into the design of the language so that it would be suitable for distributed computing.

### 2.3.3 X10 Type System

The type systems between Java and X10 differ in three ways, which are well intended to achieve X10’s parallelism goal.

1. In addition to classes, X10 adds two additional kinds of fundamental structure: *functions* and *structs*.
2. X10's generic type systems do not have the same erasure semantics as Java's generic types do. [5]
3. X10 includes constrained types, which enhances the ability to more precisely specify the acceptable values of a type by boolean expression.

### 2.3.4 Struct in X10

In X10, *struct* is a different concept from that in C, though they share the same name. *Struct* is mainly designed to improve run time performance of X10 programs. First a simple example will demonstrate the necessity of *struct*.

Assuming class Point2D is a subclass of class Point, a method call is defined as:
public def doSomething(p:Point){...}

which takes in a Point as argument. Like Java, Point2D can be taken in where Point is expected because Point2D is one kind of Point. However, the cost of this inheritance approach is not minimized.

The value passed to doSomething() for p might be the subclass Point2D of Point, or it may be some other subclasses. One only knows for sure during runtime when the value actually gets passed. It is more costly because the class Point2D may have its own implementation of some methods, for instance toString(). Specific class information has to be determined before the right method gets called.

If there were no inheritance hierarchy, the compiler itself could already determine the correct code to call, which would completely eliminate the lookup cost during runtime. That is exactly where struct comes in to play.

However, using struct requires some care:

1. No new keyword is required when initializing a struct (unlike class).
2. For struct, s1==s2 means all their fields are equal, whereas for classes, c1==c2 means they reference the exact same piece of storage. In that sense, the "equal" sign is less contingent for struct.
3. There are no references to instances of a struct, because a struct contains all the fields within itself. It is neither a reference, nor does it require a reference.

2.3.5 Distribution in X10

X10 is a language designed for distributed computing, so the ability to scale computation into distributed systems is essential. X10 provides several necessary concepts to ensure that heavy-duty concurrency can be achieved.

1. Place: an address space in which activities (like threads in Java) may run.
- No two Places have any storage in common.
- An activity at one Place may refer directly to storage at another. [6]

2. At: to designate the Place for execution by 'at(p)' where p is a Place.
- For instance:
  
  ```scala
  val result = at(p) doSomething();
  ```

  will cause the runtime to pause the calling activity and go to Place p. Then it will call 
  `doSomething()` and send the output back to this Place and assign it to the final result. 
  After that, the paused activity will continue.

3. Async: used to spawn another activity without the need to wait for current activity to 
   finish.

4. Finish: enclose a block of code to ensure that all activities inside such a block have 
   finished before continuing outside the block.

### 2.3.6 X10's Race-Condition Prevention Mechanism

Besides having types like Double and Lon, X10 also has distributed computing specific 
types like `atomic`. For example:

```scala
atomic count += 1;
```

As self-explanatory as the declaration statement already is, the variable count can only be 
updated atomically, which means if one thread is updating the variable, all other threads 
will be locked out until the first thread finishes updating and releases the lock.

A better way to do it is using AtomicLong:

```scala
val count = new AtomicLong(0);
```

In this case, the count is declared as an `AtomicLong` type, which is more specific than 
`atomic`. Even though the runtime system can figure out the specific type of the variable 
`count` eventually in the first example, it always takes time to infer that information.
3. Performance Comparisons

X10 is in a stage where it borrows the runtime mechanism from either C++ or Java. That means X10 can be compiled into either Java byte codes or C++ binaries. Its higher level nature may indicate a possibility of performance loss. Whether X10's design concept is actually helping the performance should be tested with real world performance observations.

As of June 2011, X10's Java-backend is still significantly faster than the C++-backend. [7] Therefore, the comparison will be X10's best performance that comes out of its Java-backend implementation versus its counterpart in original Java code. The X10 experiment is based on X10 version 2.2 specifications [8]. Due to constant modifications between X10 versions, programs written under version 2.2 are not compatible with compilers of early versions.

3.1 Presentation Format

The same presentation format will be applied on every implementation to ensure a clear comparison:

1. Algorithm description: a brief description of the nature of the algorithm and its run time characteristics.
2. Input and output: defines the type of input and expected type of output.
3. Java multi-threaded implementation with specified samples of input and corresponding output collected.
4. X10 implementation with same set of samples of input and corresponding output collected.
3.2 MergeSort

3.2.1 Algorithm Description
MergeSort is a well-known algorithm based on the divide-and-conquer concept. It divides the unsorted list into n sub-lists, each containing 1 element. Then it repeatedly merges sub-lists to produce new sub-lists until there is only 1 sub-list remaining. [9]

3.2.2 Input and Output
Input: an array of size n of unsorted elements
Output: a sorted array and the time spent sorting

3.2.3 Java Multi-Threaded Implementation
The multi-threaded implementation will adopt the same merge() operation when merging two sequences of sorted numbers. The difference from the sequential approach though is that more than one thread will be responsible for the sub-sequences, so that they can be executed at the same time.

A MergeRunnable class is defined to make sure each MergeRunnable is responsible for a certain sub-sequence.

```java
class MergeRunnable implements Runnable{
    public void run(){
        // Do this runnable’s share of merge sort
    }
}
```

By creating threads with different runnables, a sequence can be sorted after each thread has finished its task and merged together. A two threaded implementation with its running time being recorded is as follows:
For the above implementation, sequences of random numbers will be the input and the resulting running time elapsed will be recorded. The result is shown in Table 1 along with the result of X10 implementation.

3.2.4 X10 Implementation

X10 has its own way of declaring arrays, which will be evaluated more in later sections:

```scala
//Create arrays to be sorted
val arraySize = Int.parse(args(0));
val region = 1..arraySize;
val array:Array[Int] = new Array[Int](regionArray, (Point) => 0);
```

The algorithmic execution stays the same with its Java implementation counterpart to ensure the comparison is fair. The same timing mechanism is utilized to record its execution time as well.
3.2.5 Result Comparison

Table 1 is the result based on different input sizes as well as both Java and X10 implementations:

<table>
<thead>
<tr>
<th>SIZE</th>
<th>Java Sequential</th>
<th>Java Parallel x2</th>
<th>X10 Sequential</th>
<th>X10 Parallel x2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500</td>
<td>6</td>
<td>6</td>
<td>135</td>
<td>40</td>
</tr>
<tr>
<td>5000</td>
<td>14</td>
<td>4</td>
<td>168</td>
<td>15</td>
</tr>
<tr>
<td>10000</td>
<td>23</td>
<td>9</td>
<td>178</td>
<td>21</td>
</tr>
<tr>
<td>20000</td>
<td>20</td>
<td>4</td>
<td>194</td>
<td>50</td>
</tr>
<tr>
<td>40000</td>
<td>20</td>
<td>10</td>
<td>239</td>
<td>92</td>
</tr>
<tr>
<td>80000</td>
<td>27</td>
<td>14</td>
<td>317</td>
<td>167</td>
</tr>
<tr>
<td>160000</td>
<td>43</td>
<td>28</td>
<td>528</td>
<td>349</td>
</tr>
<tr>
<td>320000</td>
<td>90</td>
<td>36</td>
<td>881</td>
<td>668</td>
</tr>
<tr>
<td>640000</td>
<td>153</td>
<td>82</td>
<td>1567</td>
<td>1320</td>
</tr>
<tr>
<td>1280000</td>
<td>273</td>
<td>136</td>
<td>2949</td>
<td>2511</td>
</tr>
<tr>
<td>2560000</td>
<td>629</td>
<td>260</td>
<td>5661</td>
<td>5322</td>
</tr>
<tr>
<td>5120000</td>
<td>1019</td>
<td>496</td>
<td>11446</td>
<td>10969</td>
</tr>
</tbody>
</table>

Table 1: Result on MergeSort using Java/X10 (In Milliseconds)

It is shown clearly, that in this case, X10 takes almost 10 times the amount of time to finish the same task, which is disappointing. However, some additional tweaks may be applied to better take advantage of X10’s nature. A little tweak will reveal a subtle but crucial point when programming in the X10 language.
3.2.6 Optimizing X10 Implementation

The above comparison is disappointing on X10’s part. The reasons can be listed after some investigation:

1. X10’s Array class is more general than Java’s. Array in X10 supports multi-dimensional arrays over arbitrary regions. It is very important to tell the X10 compiler statically that the Array is a 1-dimensional, dense, zero-based array in the above experiment.
2. When X10 code with tight loops over arrays is compiled, the ‘-O’ option is very helpful in enhancing the performance of the loop.

With the above issues being taken care of, the X10 implementation of MergeSort is modified to the following:

```java
//Create an array to be sorted.
val arraySize = Int.parse(args(0));
var Array1:Rail[Int] = new Rail[Int](arraySize);
var Array2:Rail[Int] = new Rail[Int](arraySize);
```

`Rail[T]` is a typedef for `Array[T]{rank==1, zeroBased, rect}`, where the rank of the array is 1 (one dimensional) and the base is 0 (first index starts from 0). Accordingly, all the indexes in the above implementation are updated to adapt that.

The result is shown in Table 2 and Table 3. In addition to the optimized X10 code, the thread number is scaled up to 8 this time.
Testing Machine: 
CPU: AMD FX-8120 Eight-Core 
RAM: 8GB 
L2 Cache: 8MB 
L3 Cache: 8GB

<table>
<thead>
<tr>
<th>SIZE</th>
<th>Java Sequential</th>
<th>Java Parallel x2</th>
<th>Java Parallel x4</th>
<th>Java Parallel x8</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>5000</td>
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<td>10000</td>
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<td>12</td>
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<td>95</td>
</tr>
<tr>
<td>2560000</td>
<td>629</td>
<td>260</td>
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<td>125</td>
</tr>
<tr>
<td>5120000</td>
<td>1019</td>
<td>496</td>
<td>496</td>
<td>271</td>
</tr>
</tbody>
</table>

Table 2: Result of MergeSort using Java (In Milliseconds)

<table>
<thead>
<tr>
<th>SIZE</th>
<th>X10 Sequential</th>
<th>X10 Parallel x2</th>
<th>X10 Parallel x4</th>
<th>X10 Parallel x8</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500</td>
<td>53</td>
<td>41</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>5000</td>
<td>94</td>
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<tr>
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</tr>
<tr>
<td>5120000</td>
<td>4582</td>
<td>4365</td>
<td>4261</td>
<td>4200</td>
</tr>
</tbody>
</table>

Table 3: Optimized Result of MergeSort using X10 (In Milliseconds)
Chart 1: Comparison of X10 Performance Before and After Optimization

In comparison to non-optimized X10 code, the optimized code does have a significantly better result with 4365 milliseconds as opposed to 10969 milliseconds on the same size of 5,120,000 elements when using two threads.

However, it is still significantly slower than Java’s implementation, both sequential and parallel. Also, the parallel X10 code is noticeably faster than its sequential counterpart only until a certain size. With a 40000 elements array, the eight-thread parallel implementation takes 21.05% of what the sequential implementation takes to finish, while with a 5,120,000 input size, the number is 91.66%. With Java’s 26.59% on the exact same input size, X10’s parallel performance still has a long way to improve.
3.3 QuickSort

3.3.1 Algorithm Description
QuickSort, also known as “partition-exchange sort”, is a comparison sort that requires \(O(n \log n)\) comparisons on average and, in efficient implementations, is not a stable sort. QuickSort can be implemented with an in-place partitioning algorithm, so the entire sort can be done with only \(O(\log n)\) additional space [10].

3.3.2 Input and Output
Input: an array of size \(n\) of unsorted elements
Output: a sorted array and the time spent sorting
3.3.3 Java Multi-Threaded Implementation

Similar to the implementation of MergeSort, each thread is responsible for a certain portion of the sequence, except that for QuickSort, no merging is required.

In QuickSorter.java, the actual quickSort method is defined:

```java
public void quickSort(int p, int r){
    if(p<r){
        Splitter sp = new Splitter(array);
        int i = sp.split(p, r);
        quickSort(p, i-1);
        quickSort(i+1, r);
    }
}
```

QuickRunnable.java is created for Java’s multi-thread implementation (X10 implementation can spare those lines of code because it does not need any Runnables):

```java
public QuickRunnable(int[] array, int p, int r){
    this.array = array;
    this.p = p;
    this.r = r;
}

public void run(){
    QuickSorter qs = new QuickSorter(array);
    qs.quickSort(p, r);
}
```

When the program is running, same timing mechanism is used:
The result is shown in Table 4 along with the result of the X10 implementation.

### 3.3.4 X10 Implementation

With exactly the same algorithm, the X10 implementation will use `async` to spawn out threads. This time `Rail[T]`, along with other optimizing techniques, are used:

```java
if (p < r){
    var sp:Splitter = new Splitter();
    var i:Int = sp.split(array, p, r);
    if (thread == i){
        quickSort(array, p, i-1);
        quickSort(array, i+1, r);
    } else{
        finish{
            async quickSort(array, p, i-1, thread/2);
            async quickSort(array, i+1, r, thread/2);
        }
    }
}
```

### 3.3.5 Result Comparison

Table 4 is the comparison results based on different input sizes on multiple runs:
<table>
<thead>
<tr>
<th>SIZE</th>
<th>Java Sequential</th>
<th>Java Parallel x2</th>
<th>Java Parallel x4</th>
<th>Java Parallel x8</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500</td>
<td>9</td>
<td>6</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5000</td>
<td>13</td>
<td>11</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>10000</td>
<td>22</td>
<td>9</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>20000</td>
<td>28</td>
<td>7</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>40000</td>
<td>42</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>80000</td>
<td>41</td>
<td>6</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>160000</td>
<td>46</td>
<td>22</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>320000</td>
<td>88</td>
<td>42</td>
<td>46</td>
<td>32</td>
</tr>
<tr>
<td>640000</td>
<td>181</td>
<td>111</td>
<td>79</td>
<td>69</td>
</tr>
<tr>
<td>1280000</td>
<td>695</td>
<td>342</td>
<td>303</td>
<td>288</td>
</tr>
<tr>
<td>2560000</td>
<td>1982</td>
<td>1349</td>
<td>1212</td>
<td>1016</td>
</tr>
<tr>
<td>5120000</td>
<td>9241</td>
<td>5077</td>
<td>3449</td>
<td>2659</td>
</tr>
</tbody>
</table>

Table 4: Result of QuickSort based on Different Sizes using Java (In Milliseconds)

<table>
<thead>
<tr>
<th>SIZE</th>
<th>X10 Sequential</th>
<th>X10 Parallel x2</th>
<th>X10 Parallel x4</th>
<th>X10 Parallel x8</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500</td>
<td>18</td>
<td>4</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>5000</td>
<td>25</td>
<td>7</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>10000</td>
<td>84</td>
<td>7</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>20000</td>
<td>86</td>
<td>10</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>40000</td>
<td>83</td>
<td>35</td>
<td>21</td>
<td>43</td>
</tr>
<tr>
<td>80000</td>
<td>110</td>
<td>69</td>
<td>57</td>
<td>70</td>
</tr>
<tr>
<td>160000</td>
<td>238</td>
<td>169</td>
<td>199</td>
<td>148</td>
</tr>
<tr>
<td>320000</td>
<td>638</td>
<td>535</td>
<td>575</td>
<td>454</td>
</tr>
<tr>
<td>640000</td>
<td>1848</td>
<td>1470</td>
<td>1499</td>
<td>1456</td>
</tr>
<tr>
<td>1280000</td>
<td>5869</td>
<td>5603</td>
<td>5655</td>
<td>5602</td>
</tr>
<tr>
<td>2560000</td>
<td>22193</td>
<td>22135</td>
<td>22033</td>
<td>22465</td>
</tr>
<tr>
<td>5120000</td>
<td>84469</td>
<td>84281</td>
<td>84753</td>
<td>85005</td>
</tr>
</tbody>
</table>

Table 5: Result of QuickSort based on Different Sizes using X10 (In Milliseconds)
X10 has a similar performance as in the merge sort test case, which is one tenth of Java's performance. One interesting observation is that both programs’ optimal input size for performance is between 80000 and 160000. This is due to the machine's CPU cache and memory where the AMD FX8120 has eight cores with 8MB L2 cache and 8MB L3 cache for each core. After the cache is filled up when taking in a large size of input, the speed will be noticeably slower when RAM kicks in.

Chart 3 and Chart 4 illustrate this difference clearly. With a 5,120,000-element array, X10's sequential and parallel implementations yield almost no different outcome; on the other hand, with fewer than 80,000 elements, the parallel version is truly faster.

(Vertical Axis in miliseconds; Horizontal Axis represents number of input)

Chart 3: Comparison of performance between Java and X10
Chart 4: Comparison of performance of X10 with Smaller Input Size

Even with faster parallel performance, which is expected, X10's performance on shared memory is still not comparable to Java's.
3.4 Strassen Matrix Multiplication

3.4.1 Algorithm Description

Strassen introduced an algorithm in 1969 to multiply M x M matrices, which has a lower complexity than the traditional $O(M^3)$ [11]. The algorithm is presented in Figure 1. It demonstrates the scheme for the product of two 2 x 2 matrices. This scheme involves seven multiplications and 18 additions instead of the usual eight multiplications and four additions for two 2 x 2 matrices.

Input : Matrices $A$, $B$

Phase 1

$T_1 = A_{11} + A_{22}$  $T_6 = B_{11} + B_{22}$

$T_2 = A_{21} + A_{22}$  $T_7 = B_{12} - B_{22}$

$T_3 = A_{11} + A_{12}$  $T_8 = B_{21} - B_{11}$

$T_4 = A_{21} - A_{11}$  $T_9 = B_{11} + B_{12}$

$T_5 = A_{12} - A_{22}$  $T_{10} = B_{21} + B_{22}$

Phase 2

$Q_1 = T_1 * T_6$  $Q_5 = T_3 * B_{22}$

$Q_2 = T_2 * B_{11}$  $Q_6 = T_4 * T_9$

$Q_3 = A_{11} * T_7$  $Q_7 = T_5 * T_{10}$

$Q_4 = A_{22} * T_8$

Phase 3

$U_1 = Q_1 + Q_4$  $U_2 = Q_5 - Q_7$

$U_3 = Q_3 + Q_1$  $U_4 = Q_2 - Q_6$

$C_{11} = U_1 - U_2$  $C_{12} = Q_3 + Q_5$

$C_{21} = Q_2 + Q_4$  $C_{22} = U_3 - U_4$

Output : $C = (C_{ij})$

Figure 1: Strassen’s Matrix Multiplication Algorithm

From a parallel processing point of view, the above calculations can be parallelized whenever no dependency of execution exists. For example, $T_1 = A_{11} + A_{22}$ and $T_6 = B_{11} + B_{22}$ are two executions that have no dependency upon one another. However, any calculations from different phases are subject to the dependency barrier. $Q_1 = T_1 * T_6$ has to wait until $T_1$ and $T_6$ get their values after Phase 1.
With that in mind, programs that parallelize the calculation of the product of two 16 x 16 matrices are written to compare between Java and X10.

### 3.4.2 Java Multi-Threaded Implementation

With Java, Threads and Runnables are used again for consistency throughout the experiment. For an eight-thread implementation, eight Runnables have to be constructed to get the job done.

```java
MatrixRunnable m1 = new MatrixRunnable(x, 0, 0, a, size);
MatrixRunnable m2 = new MatrixRunnable(x, 0, 1, b, size);
MatrixRunnable m3 = new MatrixRunnable(x, 1, 0, c, size);
MatrixRunnable m4 = new MatrixRunnable(x, 1, 1, d, size);
MatrixRunnable m5 = new MatrixRunnable(y, 0, 0, e, size);
MatrixRunnable m6 = new MatrixRunnable(y, 0, 1, f, size);
MatrixRunnable m7 = new MatrixRunnable(y, 1, 0, g, size);
MatrixRunnable m8 = new MatrixRunnable(y, 1, 1, h, size);
```

Each thread is doing its own share of calculation in each phase of the Strassen Matrix Multiplication.

The result of Java’s performance is shown in Table 6 along with X10’s performance result.

### 3.4.3 X10 Implementation

Again, X10 implementation adapts the same algorithm with specific X10 programming language optimization:

```java
finish{
    async submatrix(x, 0, 0, a, size);
    async submatrix(x, 0, 1, b, size);
    async submatrix(x, 1, 0, c, size);
    async submatrix(x, 1, 1, d, size);
    async submatrix(y, 0, 0, e, size);
    async submatrix(y, 0, 1, f, size);
    async submatrix(y, 1, 0, g, size);
    async submatrix(y, 1, 1, h, size);
}
```
Since the thread-spawning has to happen several times through the program. X10’s “Runnable Free” syntax saves quite a few lines of code.

### 3.4.4 Result Comparison

Table 6 is the comparison results based on random generated matrices on multiple runs:

<table>
<thead>
<tr>
<th>Run #</th>
<th>Java Sequential</th>
<th>Java x8</th>
<th>X10 Sequential</th>
<th>X10 x8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>231</td>
<td>158</td>
<td>377</td>
<td>294</td>
</tr>
<tr>
<td>2</td>
<td>198</td>
<td>131</td>
<td>396</td>
<td>309</td>
</tr>
<tr>
<td>3</td>
<td>207</td>
<td>146</td>
<td>298</td>
<td>265</td>
</tr>
<tr>
<td>4</td>
<td>232</td>
<td>143</td>
<td>325</td>
<td>287</td>
</tr>
<tr>
<td>5</td>
<td>209</td>
<td>142</td>
<td>366</td>
<td>298</td>
</tr>
<tr>
<td>6</td>
<td>204</td>
<td>179</td>
<td>372</td>
<td>291</td>
</tr>
<tr>
<td>7</td>
<td>208</td>
<td>152</td>
<td>309</td>
<td>259</td>
</tr>
<tr>
<td>8</td>
<td>223</td>
<td>142</td>
<td>361</td>
<td>278</td>
</tr>
<tr>
<td>9</td>
<td>233</td>
<td>135</td>
<td>332</td>
<td>266</td>
</tr>
<tr>
<td>10</td>
<td>202</td>
<td>155</td>
<td>351</td>
<td>284</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>214.7</strong></td>
<td><strong>148.3</strong></td>
<td><strong>348.7</strong></td>
<td><strong>283.1</strong></td>
</tr>
</tbody>
</table>

Table 6: Result Comparison of Strassen’s Matrix Multiplication (In Milliseconds)

With 16 x 16 matrices multiplication, the eight-thread parallel implementation of Java takes 69.07% of what the sequential implementation takes to finish, while X10 takes 81.19%. The parallel implementation is not significantly faster because only part of the algorithm is parallelizable; however, X10 still shows less impressive results compared to Java.
3.5 \( \pi \) Calculation

Another performance criterion is how efficiently each thread accesses shared atomic variables. [12] A comparison is conducted using the algorithm to compute \( \pi \).

3.5.1 Monte Carlo Method

The Monte Carlo method was introduced in the 1940s. [13] It uses probability distribution as the means to compute \( \pi \). For example, given a square of 1.0 x 1.0, one quarter of a circle is inscribed within, as shown in Figure 2. If objects are uniformly scattered within the square, the ratio of the number of objects in blue (inside the circle) and the number of objects in white (outside the circle) should equal \( \pi/4 \).

![Figure 2: Monte Carlo method on \( \pi \) calculation](image)

Because the Monte Carlo method is essentially about the count of objects, programs can be written to test the performance of the efficiency of how the count is updated. With that in mind, both Java and X10 implementations do not use local counts; instead, every
update of the shared count happens after one thread determines whether or not the object is inside the circle.

### 3.5.2 Java Multi-Threaded Implementation

Java’s implementation creates four threads, each being forced to access the shared variable \textit{count}:

```java
public static class PiRunnable implements Runnable{
    private int n;

    public PiRunnable(int n){
        this.n = n;
    }

    @Override
    public void run() {
        Random ranGen = new Random();
        float x, y;
        for (int j=0; j<n; j++){
            x = ranGen.nextFloat();
            y = ranGen.nextFloat();
            if (inCircle(x, y)){
                count.incrementAndGet();
            }
        }

        public boolean inCircle(float x, float y){
            return x*x+y*y <= 1.0 ? true : false;
        }
    }
}
```

The result is shown in Table 7 along with X10’s performance result.

### 3.5.3 X10 Implementation

X10 adopts the exact same implementation to coerce each thread to compete for one shared variable:
3.5.4 Result comparison

Table 7 is the comparison results based on different input sizes on multiple runs:

<table>
<thead>
<tr>
<th>Size of Domain</th>
<th>Java</th>
<th>X10</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>5000</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>10000</td>
<td>18</td>
<td>35</td>
</tr>
<tr>
<td>20000</td>
<td>23</td>
<td>49</td>
</tr>
<tr>
<td>40000</td>
<td>30</td>
<td>53</td>
</tr>
<tr>
<td>80000</td>
<td>38</td>
<td>91</td>
</tr>
<tr>
<td>160000</td>
<td>58</td>
<td>95</td>
</tr>
<tr>
<td>320000</td>
<td>98</td>
<td>182</td>
</tr>
<tr>
<td>640000</td>
<td>154</td>
<td>238</td>
</tr>
<tr>
<td>1280000</td>
<td>349</td>
<td>405</td>
</tr>
<tr>
<td>2560000</td>
<td>724</td>
<td>862</td>
</tr>
<tr>
<td>5120000</td>
<td>1523</td>
<td>1329</td>
</tr>
</tbody>
</table>

Table 7: Result Comparison of π calculation (In Milliseconds)
X10’s performance shows a slight edge this time when the input size is very large.

(Vertical Axis in milliseconds; Horizontal Axis represents size of domain)

Chart 5: Comparison of performance of $\pi$ calculation
On an input size of 1,000,000, where the atomic variable \textit{count} gets updated for hundreds of thousands of time, X10’s performance is significantly better:

<table>
<thead>
<tr>
<th>Run #</th>
<th>Java</th>
<th>X10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4179</td>
<td>1960</td>
</tr>
<tr>
<td>2</td>
<td>3879</td>
<td>2123</td>
</tr>
<tr>
<td>3</td>
<td>4221</td>
<td>2052</td>
</tr>
<tr>
<td>4</td>
<td>4087</td>
<td>2050</td>
</tr>
<tr>
<td>5</td>
<td>4107</td>
<td>2037</td>
</tr>
<tr>
<td>6</td>
<td>3703</td>
<td>2005</td>
</tr>
<tr>
<td>7</td>
<td>4371</td>
<td>1923</td>
</tr>
<tr>
<td>8</td>
<td>4186</td>
<td>1988</td>
</tr>
<tr>
<td>9</td>
<td>3922</td>
<td>2068</td>
</tr>
<tr>
<td>10</td>
<td>4108</td>
<td>2000</td>
</tr>
<tr>
<td>Average</td>
<td>4076.3</td>
<td>2020.6</td>
</tr>
</tbody>
</table>

Table 8: Result Comparison of \( \pi \) calculation on input size of 1,000,000 (In Milliseconds)

As shown in Table 8, X10 takes 50.43% less time than Java to calculate \( \pi \). Given the fact that X10 did poorly on almost all previous experiments, the better efficiency of updating the atomic value is very likely the reason X10 does well with \( \pi \) calculation in this case.
4. Programmability Comparison

Some of X10's programming and syntax differences were mentioned in earlier sections to illustrate X10's idealism towards distributed computing. This section will focus solely on the ease of programmability of Java and X10 in its present format.

4.1 Spawning and Synchronizing Threads

For concurrency programming, spawning and synchronizing threads is the portion of code most frequently written to support the distributed-computing purpose.

For Java, there are two ways to do this:

1. Use a Runnable object:

   The Runnable interface defines a single method, run(), meant to contain the code executed in the thread. [14] With this approach, the runnable object has to be passed in as an argument to construct a Thread object. For example:

   ```java
   public class SampleRunnable implements Runnable{
       public void run(){
           //Do the task
       }
   }
   
   Thread t = new Thread(SampleRunnable);
   t.start();
   ```

2. Subclass Thread:

   The Thread class itself implements Runnable, though its run() method does nothing. An application can subclass the Thread class, providing its own implementation of run(). For example:

   ```java
   public class SampleThread extends Thread{
   ```
public void run()
{
    //Override default behavior and do the task

}

(new SampleThread).start();

For Java, synchronizing threads would come after spawning and finishing the tasks:

try{
    thread1.join();
    thread2.join();
}
catch(InterruptedException ie){
    System.err.println(ie.toString());
}

Those few lines of code usually cannot be spared if one wants to create threads as a way to finish some tasks concurrently in Java.

For X10, spawning and synchronizing happens altogether with the following syntax:

finish{
    async{
        //Thread 1 execution
    }
    async{
        //Thread 2 execution
    }
    async{
        //Thread 3 execution
    }
}
    //All threads are synced and joined, main thread ready to go....
It is clear that X10's syntax is much simpler. No *Threads* or *Runnable* need to be explicitly created, and no method needs to be overridden like in Java. Inside each *async* block, all the lines are normal statements as if they are from a sequential program. After all threads finish their execution, no *try*{}*catch*{} blocks are needed. With *finish*{} enclosing the parallel portion, all the threads will be synchronized after they exit the *finish*{} block.

### 4.2 Functions

Functions are used extensively in many programming languages. A function takes a set of inputs; does some calculations on the inputs; and then returns a set of results.

In Java, a function is declared as following:

```java
public int calculateAnswer(int arg1, String arg2, double arg3){
    //do the calculation here
}
```

The only required elements of a method declaration are the method's return type, name, a pair of parentheses, and a body between braces.

In X10, the basic syntax for functions is:

```x10
(\text{arg1Type}, \text{arg2Type}, ...) \Rightarrow \text{returnType}
```

For example:

```x10
var computeSum: (a:Array[Float](1)) \Rightarrow Float;
```

The value of the variable of computeSum -- or in other words, the body of the function computeSum -- will be a method that takes a singly-indexed array of Floats and returns a Float.
The function body may be a block like Java's function body. For instance, to compute an integer's square value, one can use addition repeatedly:

```java
val square: (Int) => Int
  = (n: Int) => {
    var result: Int = 0;
    for (var i=0; i<n; i++)
      result += n;
    return result;
  }
```

The declaration alone, (Int)=>Int, is neat; however, a definition of an X10's function has redundant syntax as both (Int)=>Int in the first line and (n:Int)=>{} in the rest of the lines are present.

The redundant syntax may have special purposes, one of them is to make sure that the function can be taken as an object.

### 4.2.1 Function as an Object

It is sometimes possible to need a function as an argument for another function's parameter list.

In Java, a common pattern would be to wrap a function body within an interface. For example, the interface Callable can achieve that purpose. Any class that implements Callable will have to override its call():

```java
public T funcToBePassed(){
    //do something
}
public void funcTakesAnotherFunc(Callable<T> func){
    //do something
}
```
When calling the \texttt{funcTakeAnotherFunc()}, using an anonymous class will achieve the goal:

\begin{verbatim}
funcTakeAnotherFunc(new Callable<T>()
    public T call()
        return funcToBePassed();
    }

\end{verbatim}

In X10, because a function has already been assigned to a named variable, the above task, which requires more care for Java, would be trivial for X10:

\begin{verbatim}
val r = new Random();
val rand = ()=>r.nextDouble();
val calculationUsingRandomNumber = calculateSomething(rand);
\end{verbatim}

where \texttt{rand} in the above example is a function that takes no argument and returns a random number each time it is called.

\subsection*{4.3 Array}

In Java, a one-dimensional array's declaration and assignment is as trivial as possible:

\begin{verbatim}
int[] anArray = new int[10];
anArray[0] = 100;
...
\end{verbatim}

The case for two-dimensional arrays is not too much more complicated than that for one-dimensional arrays:

\begin{verbatim}
int[][] rank2Array = new int[10][15];
rank2Array[0][0] = 100;
...
\end{verbatim}
or if the assignment has some rules, then the syntax should be as follows:

```java
for(int i=0; i<10; i++){
    for(int j=0; j<15; j++)
        //assignment
}
```

However, 3-tuples, 4-tuples and even more tupled arrays will be complicated to initialize and present.

In X10, the array system introduces the concept of Points and Regions. A Point corresponds to an element in the array that is of the rank of n (n-tuples), while Regions are the domains within which the Point can define.

For one-dimensional arrays, the syntax of X10 is a bit cumbersome to use considering the simple nature of such arrays.

```java
val region = 1..15; //assume an array of size 15
var anArray:Array[Int](1) = new Array[Int](1)(region, (Point)=>0);
```

For two dimensional arrays, the scale of the matrix is defined with Region:

```java
var region = (1...10)*(1...15);
var anArray = new Array[Int](region, (Point)=>0);
```

A `for` loop can also be used for the assignment of the array.

```java
for(int i=0; i<10; i++){
    for(int j=0; j<15; j++)
        //assignment
}
```
In fact, the syntax of both languages is similar in terms of complexity for Arrays. X10 proposes the Region and Point approach for performance consideration. However, as shown in the MergeSort example, the Point implementation right now is still quite slow, especially for dense arrays. For dense arrays, better written code in terms of performance is as follows:

```java
var anArray = new Rail[Int](15);
```

This is essentially a declaration of a Java-like array.

### 4.4 Comparison based on lines of code

To have a quantitative comparison of the syntax complexity between Java and X10, it is helpful to count the lines of code each programming language needs to accomplish the same task. It needs to be noted that the comparison is merely based on a few examples, so it is more of an evaluation than a definitive answer as to which language is more simplistic in syntax.

Table 9 shows the comparison based on the examples in section 3:

<table>
<thead>
<tr>
<th>Program</th>
<th>Java (Full)</th>
<th>X10 (Full)</th>
<th>Java (Exclude Declaration)</th>
<th>X10 (Exclude Declaration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mergesort</td>
<td>161</td>
<td>99</td>
<td>116</td>
<td>71</td>
</tr>
<tr>
<td>Quicksort</td>
<td>173</td>
<td>110</td>
<td>130</td>
<td>82</td>
</tr>
<tr>
<td>Strassen</td>
<td>256</td>
<td>160</td>
<td>173</td>
<td>127</td>
</tr>
<tr>
<td>π Calculation</td>
<td>56</td>
<td>34</td>
<td>29</td>
<td>15</td>
</tr>
</tbody>
</table>

**Table 9: Comparison of Syntax Complexity (In Number of Lines of Code)**

It is shown that X10 needs fewer lines of code to execute the same task in all the test cases above. It certainly indicates the simplicity of X10’s distributed-computing syntax to some degree.
5. Tool Support

As a programming language that has been around since 1995 [15], Java is one of the most popular programming languages in the software industry. Therefore, the tool support for Java is state of the art. Many major IDEs support Java in their native mode, for example Eclipse, NetBeans and IntelliJ. They provide editors for writing and editing programs, a syntax checker to statically check the program before compilation, and debuggers for locating logic errors [16].

On the other hand, as a newer programming language, X10 has a less-evolved tool support system [17]. As of now, X10DT is the only comprehensive development tool that supports X10’s syntax and runtime debugging.

X10DT is built on top of Eclipse similar to JDT for Java. It allows programmers to edit, build, and launch the program. Help pages are also integrated into X10DT for X10 language help and X10DT usage help.

The IBM Parallel Debugger for X10 Programming [18] is integrated with X10DT for debugging purposes. It can assist the programmers to display X10 variables during runtime; set breakpoints and enable operations, such as step into, step over, pause, and resume. Although it sounds quite similar to what JDT debugger does for Java programming, the X10 debugger is much more rough-edged.

Even with X10DT, of which the primary goal is to support X10 development, some X10 specific functionalities are still missing. For example, “autocomplete” is a popular and, arguably, a must-have feature in Java development, but it is not in X10DT yet. Also, with X10DT’s debugging tool, it is hard to navigate to the erroneous lines with its less detailed console information.
These limitations do affect the productivity when developing X10 programs. However, it is reasonable to expect the tool support of X10 to improve over time to solve all these issues.
6. Conclusion

X10 is a well thought-out programming language aiming to be at least a distributed-computing alternative to Java. Overall, its syntax is traditional with its object-oriented feature. Programmers with Java or C++ programming background will find the syntax familiar and easy to acquire. Beyond that, X10 has a very simplistic distributed computing syntax, which serves its purpose as a concurrent language very well.

Furthermore, X10 introduces some original features and concepts in order to define and handle the new problems encountered with distributed computing. The idea might be good, but the execution is not there yet.

To sum it up, X10, as a new language aiming at being a distributed-computing alternative, has the following advantages and disadvantages:

Advantages:
1. It builds from the ground up with the distributed-computing concept in mind.
2. It is well designed to get rid of some complexity related to distributed-computing programming.
3. It can be compiled into both Java bytecode and C++ binaries, which gives itself a broader platform.
4. Its syntax is similar to the most popular programming languages like Java and C++, so it will be relatively easy to adopt once it is matured.

Disadvantages:
1. Its performance in most aspects is still very poor compared to a sophisticated language like Java.
2. Its tool support is very poor with a minimum static syntax checker available and few debugging tools.
3. X10 had been changed back and forth quite a bit between version 1.x and 2.x. The same code from version 1.x does not run when adopting a 2.x version compiler.

It can be noted that all of X10’s disadvantages are due to the fact that it is a very new programming language. After it matures with time, it should have no problem to be adopted considering its programmer friendly nature and structural distributed computing emphasis.
Reference


