Lecture 5: Futures — Tasks with Return Values

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Solution to Worksheet 4

- Estimate $T(S,P) \sim \frac{\text{WORK}(G,S)}{P} + \text{CPL}(G,S) = \frac{(S-1)}{P} + \log_2(S)$ for the parallel array sum computation shown in slide 4.

- Assume $S = 1024 \implies \log_2(S) = 10$

- Compute for 10, 100, 1000 processors
  - $T(P) = \frac{1023}{P} + 10$
  - Speedup(10) = $\frac{T(1)}{T(10)} = \frac{1033}{112.3} \approx 9.2$
  - Speedup(100) = $\frac{T(1)}{T(100)} = \frac{1033}{20.2} \approx 51.1$
  - Speedup(1000) = $\frac{T(1)}{T(1000)} = \frac{1033}{11.0} \approx 93.7$

- Why does the speedup not increase linearly in proportion to the number of processors?
  - Because of the critical path length, $\log_2(S)$, is a bottleneck
Worksheet 4 - Speedup Chart (linear scale)

\[ \text{speedup} = \frac{1033}{\left(\frac{1023}{p}\right) + 10} \]
Functional Parallelism: Adding Return Values to Async Tasks

Example Scenario (PseudoCode)

```java
// Parent task creates child async task
future<Integer> container = future { return computeSum(X,low,mid); };

... 

// Later, parent examines the return value
Integer sum = container.get();
```

Two issues to be addressed:

1) Distinction between `container` and value in container (box)
2) Synchronization to avoid race condition in container accesses

![Diagram showing parent and child tasks with container and return value connections]
No mutation!
future\langle T \rangle \ f = \text{future} \ \{\text{Stmt-Block}\}

- Creates a new child task to execute \text{Stmt-Block}, which \text{return}s a value of type \text{T}
- The future expression has type future\langle T \rangle

Expr.get()

- Evaluate \text{Expr}, and block if \text{Expr}'s value is unavailable
- Unlike finish which waits for all tasks in the finish scope, a \text{get()} operation only waits for the specified future task
Example: Two-way Parallel Array Sum using Future Tasks

1. // Parent Task T1 (main program)
2. // Compute sum1 (lower half) & sum2 (upper half) in parallel
3. future<Integer> sum1 = future { // Future Task T2
4.    int sum = 0;
5.    for(int i = 0; i < X.length / 2; i++) sum += X[i];
6.    return sum;
7. };
8. future<Integer> sum2 = future { // Future Task T3
9.    int sum = 0;
10.   for(int i = X.length / 2; i < X.length; i++) sum += X[i];
11.   return sum;
12. };
13. // Task T1 waits for Tasks T2 and T3 to complete
14. int total = sum1.get() + sum2.get();
Future Tasks vs. Regular Async Versions of Two-Way Array Sum

- Future task version initializes two references to future objects, sum1 and sum2
- No finish construct needed in this example
  - Instead parent task waits for child tasks by performing sum1.get() and sum2.get()
- Easier to guarantee absence of race conditions in Future Task version
  - No race on sum because it is declared as a local variable in both tasks T2 and T3
  - No race on future variables, sum1 and sum2, because of blocking-read semantics
Recursive Array Sum (Sequential version)

Sequential divide-and-conquer pattern:

1. int sum = computeSum(X, 0, X.length-1); // main
2. static int computeSum(int[] X, int lo, int hi) {
3.     if ( lo > hi ) return 0;
4.     else if ( lo == hi ) return X[lo];
5.     else {
6.         int mid = (lo+hi)/2;
7.         int sum1 =
8.             computeSum(X, lo, mid);
9.         int sum2 =
10.            computeSum(X, mid+1, hi);
11.         return sum1 + sum2;
12.     }
13. } // computeSum
Recursive Array Sum using Future Tasks
(Two futures per method call)

Parallel divide-and-conquer pattern:

1. int sum = computeSum(X, 0, X.length-1); // main
2. static int computeSum(int[] X, int lo, int hi) {
3.     if ( lo > hi ) return 0;
4.     else if ( lo == hi ) return X[lo];
5.     else {
6.         int mid = (lo+hi)/2;
7.         future<int> sum1 = future {
8.             computeSum(X, lo, mid); }
9.         future<int> sum2 = future {
10.            computeSum(X, mid+1, hi); }
11.         // Parent now waits for the container values
12.         return sum1.get() + sum2.get();
13.     } // computeSum
14. } // computeSum
Computation Graph Extensions for Future Tasks

- Since a get() is a blocking operation, it must occur on boundaries of CG nodes/steps
  - May require splitting a statement into sub-statements e.g.,
    - 12: int sum = sum1.get() + sum2.get();
      can be split into three sub-statements
    - 12a: int temp1 = sum1.get();
    - 12b: int temp2 = sum2.get();
    - 12c: int sum = temp1 + temp2;
- Spawn-edge connects parent task to child future task, as before
- Join-edge connects end of future task to Immediately Enclosing Finish (IEF), as before
- Additional join edges are inserted from end of future task to each get() operation on future object
CG for Two-way Parallel Array Sum using Future Tasks

```java
1. int sum = computeSum(X, 0, X.length-1); // main
2. static int computeSum(int[] X, int lo, int hi) {
3.   if ( lo > hi ) return 0;
4.   else if ( lo == hi ) return X[lo];
5.   else {
6.     int mid = (lo+hi)/2;
7.     future<int> sum1 = future {
8.       computeSum(X, lo, mid); }
9.     future<int> sum2 = future {
10.    computeSum(X, mid+1, hi); }
11.    // Parent now waits for the container values
12.    return sum1.get() + sum2.get();
13. }
14.} // computeSum
```

Computation graph of the program from Slide 9 when input array has length of 2

Stmt8 = Future task for sum1
Stmt10 = Future task for sum2
CG for Two-way Parallel Array Sum using Future Tasks

1. int sum = computeSum(X, 0, X.length-1); // main
2. static int computeSum(int[] X, int lo, int hi) {
3. if (lo > hi) return 0;
4. else if (lo == hi) return X[lo];
5. else {
6. int mid = (lo+hi)/2;
7. future<int> sum1 = future {
8. computeSum(X, lo, mid); };
9. future<int> sum2 = future {
10. computeSum(X, mid+1, hi); };
11. // Parent now waits for the container values
12. return sum1.get() + sum2.get();
13. }
14.} // computeSum

// Where should doWork() for + be placed?
12a: int temp1 = sum1.get();
12b: int temp2 = sum2.get();
12c: int sum = temp1 + temp2;

Computation graph of the program from Slide 9 when input array has length of 2

Stmt8 = Future task for sum1

Stmt10 = Future task for sum2
Announcements & Reminders

• IMPORTANT:
  – Watch video & read handout for topic 2.3 for next lecture on Wednesday, Jan 24th

• Lab1 is due TODAY at 11:59PM

• HW1 was posted on the course web site (http://comp322.rice.edu) on Jan 10th, and is due on Jan 24th

• Quiz for Unit 1 (topics 1.1 - 1.5) is due by Friday, Jan 26th on Canvas

• See course web site for all work assignments and due dates

• Use Piazza (public or private posts, as appropriate) for all communications re. COMP 322

• See Office Hours link on course web site for latest office hours schedule.