COMP 322: Fundamentals of Parallel Programming

Lecture 5: Futures — Tasks with Return Values

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Solution to Worksheet 4

- Estimate T(S,P) ~ WORK(G,S)/P + CPL(G,S) = (S-1)/P + log2(S) for the parallel array sum computation shown in slide 4.
- Assume S = 1024 ==> log2(S) = 10
- Compute for 10, 100, 1000 processors
  - T(P) = 1023/P + 10
  - Speedup(10) = T(1)/T(10) = 1033/112.3 ~ 9.2
  - Speedup(100) = T(1)/T(100) = 1033/20.2 ~ 51.1
  - Speedup(1000) = T(1)/T(1000) = 1033/11.0 ~ 93.7
- Why does the speedup not increase linearly in proportion to the number of processors?
  - Because of the critical path length, log2(S), is a bottleneck

Extending Async Tasks with Return Values

Example Scenario (PseudoCode)

```
// Parent task creates child async task
final future container =
                  async { return computeSum(X, low, mid); };
. . .
// Later, parent examines the return value
int 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

Parent Task

```
container = async {...}
. . .
container.get()
```

Child Task

```
computeSum(...)
return ...
```

container → return value

HJ Futures: Tasks with Return Values

`async { Stmt-Block }`

- Creates a new child task that executes Stmt-Block, which must terminate with a return statement and return value
- Async expression returns a reference to a *container* of type future

`Expr.get()`

- Evaluates Expr, and blocks if Expr's value is unavailable
- Unlike finish which waits for *all* tasks in the finish scope, a get() operation only waits for the specified async expression

Example: Two-way Parallel Array Sum using Future Tasks (PseudoCode)

```
// Parent Task T1 (main program)
// Compute sum1 (lower half) & sum2 (upper half) in parallel
final future sum1 = async { // Future Task T2
  int sum = 0;
  for(int i=0 ; i < X.length/2 ; i++) sum += X[i];
  return sum;
};
final future sum2 = async { // Future Task T3
  int sum = 0;
  for(int i=X.length/2 ; i < X.length ; i++) sum += X[i];
  return sum;
};
//Task T1 waits for Tasks T2 and T3 to complete
int total = sum1.get() + sum2.get();
```

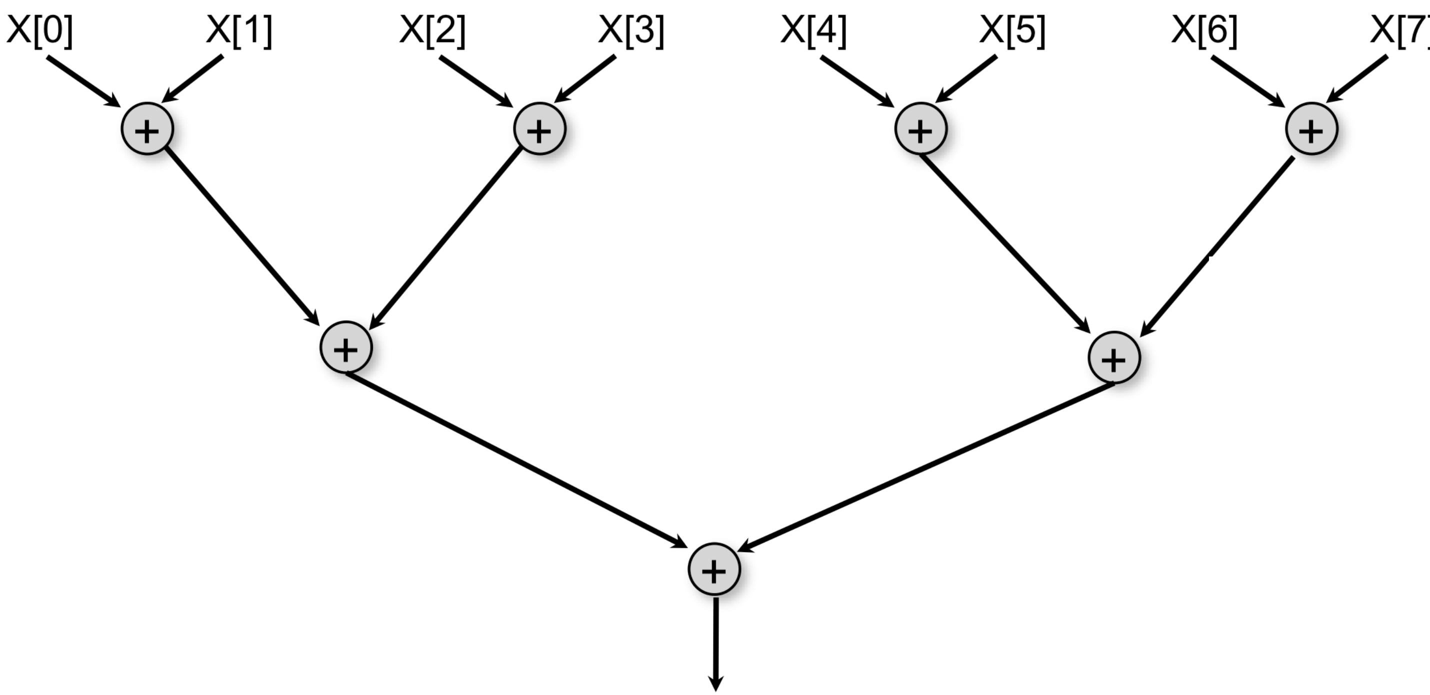
Future Task Declarations and Uses

- Variable of type future is a reference to a **future object**
  - Container for return value from future task
  - The reference to the container is also known as a "handle"
- Two operations that can be performed on variable V of type future:
  - Assignment: V1 can be assigned value of type future
  - Blocking read: V1.get() waits until the future task referred to by V1 has completed, and then propagates the return value

Comparison of Future Task and Regular Async Versions of Two-Way Array Sum

- Future task version initializes two references to future objects, sum1 and sum2, and both are declared as final
- 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

Reduction Tree Schema for computing Array Sum in parallel



Question:

- How can we implement this schema using future tasks instead of async tasks?

Array Sum using Future Tasks (Seq version)

Recursive divide-and-conquer pattern

```
static int computeSum(int[] X, int lo, int hi) {
    if ( lo > hi ) return 0;
    else if ( lo == hi ) return X[lo];
    else {
      int mid = (lo+hi)/2;
      final sum1 = computeSum(X, lo, mid);
      final sum2 = computeSum(X, mid+1, hi);
     // Parent now waits for the container values
      return sum1 + sum2;
    }
  } // computeSum
int sum = computeSum(X, 0, X.length-1); // main program
```

Array Sum using Future Tasks (two futures per method call)

Recursive divide-and-conquer pattern

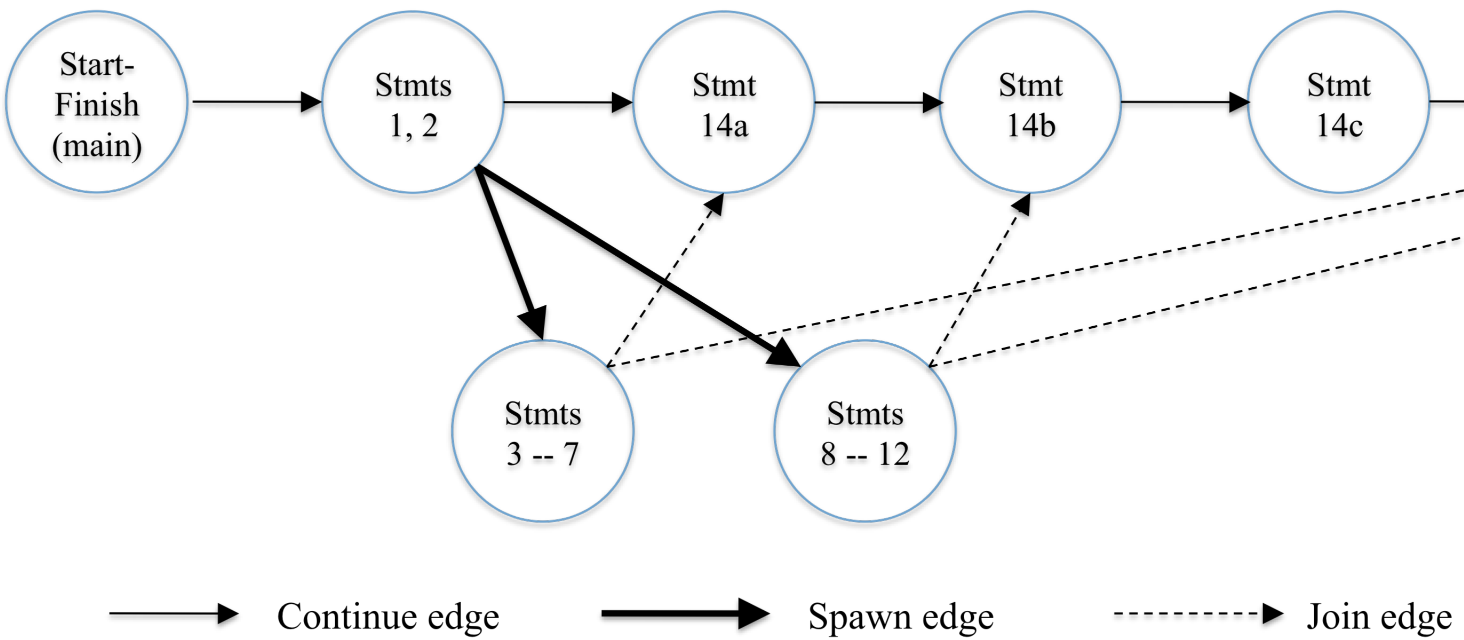
```
// Parent Task T1 (main program)
// Compute sum1 (lower half) and sum2 (upper half) in parallel
final future<int> sum1 = async<int> { // Future Task T2
  int sum = 0;
  for(int i=0 ; i<X.length/2 ; i++) sum+=X[i];
  return sum;
};
future<int> sum2 = async<int> { // Future Task T3
  int sum = 0;
  for(int i=X.length/2 ; i<X.length ; i++)sum+=X[i];
  return sum;
};
//Task T1 waits for Tasks T2 and T3 to complete
int sum = sum1.get() + sum2.get();
```

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.,
    - 14: int sum = sum1.get() + sum2.get();

    can be split into three sub-statements
    - 14a int temp1 = sum1.get();
    - 14b int temp2 = sum2.get();
    - 14c 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

Computation Graph for Two-way Parallel Array Sum using Future Tasks

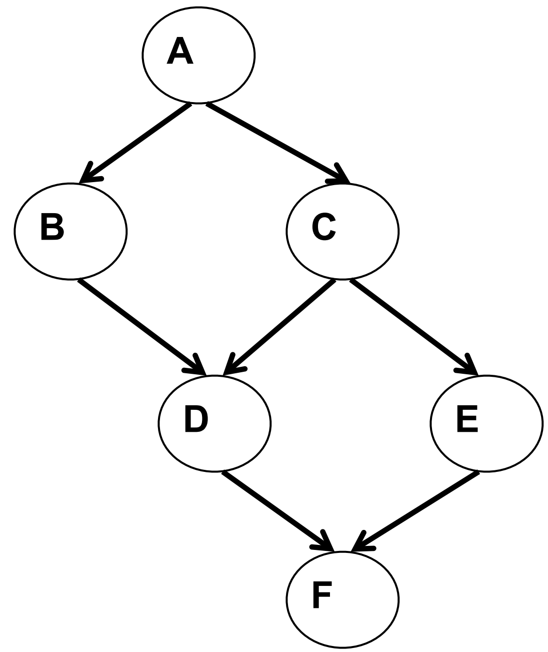


Worksheet #5: Computation Graphs for Async-Finish and Future Constructs

Name: ______________________ Netid: ______________________

1) Can you write pseudocode with async-finish constructs that generates a Computation Graph with the same ordering constraints as the graph on the right? If so, provide a sketch of the program.

2) Can you write pseudocode with future async-get constructs that generates a Computation Graph with the same ordering constraints as the graph on the right? If so, provide a sketch of the program.



Use the space below for your answers