COMP 322: Fundamentals of Parallel Programming

Lecture 5: Futures — Tasks with Return Values

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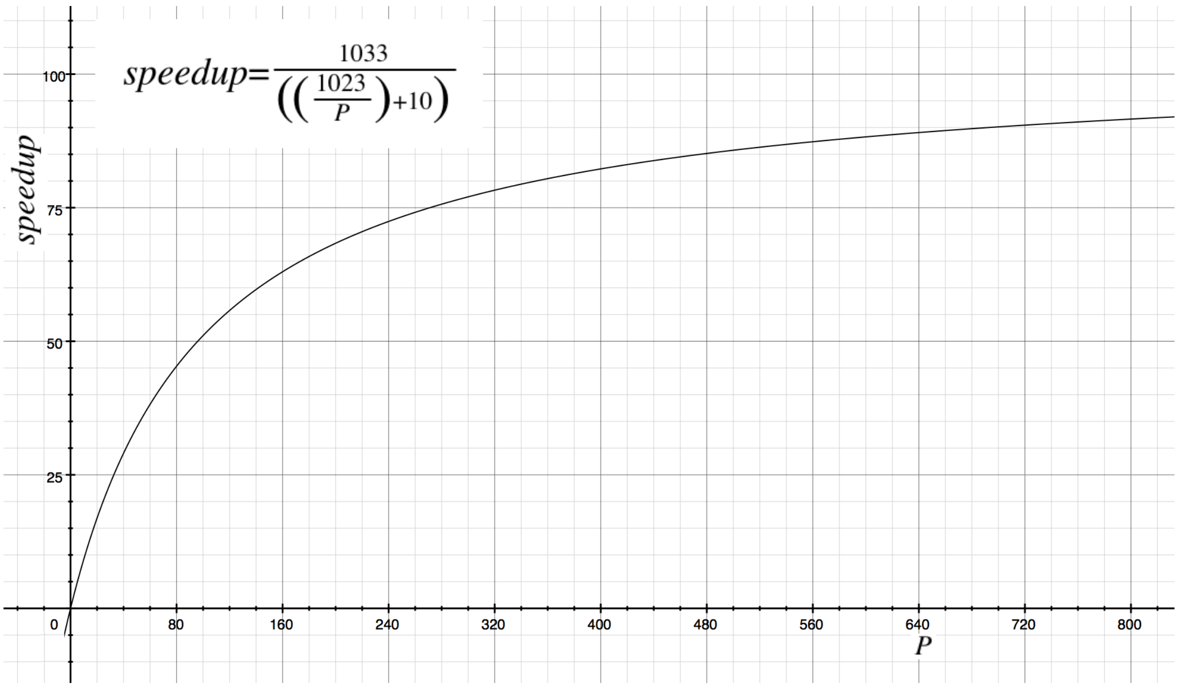
Solution to Worksheet 4

- 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

Worksheet 4 - Speedup Chart (linear scale)



Functional Parallelism: Adding Return Values to Async Tasks

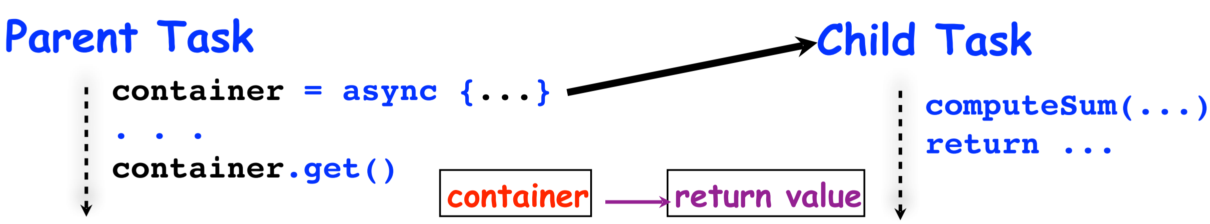
Example Scenario (PseudoCode)

```
// Parent task creates child async task
future<int> 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



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
future<int> sum1 = async { // Future Task T2
  int sum = 0;
  for(int i = 0; i < X.length / 2; i++) sum += X[i];
  return sum;
};
future<int> 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: V can be assigned value of type future
  - — Blocking read: V.get() waits until the future task referred to by V 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
- 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:

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


Recursive Array Sum using Future Tasks (Two futures per method call)

Parallel divide-and-conquer pattern:

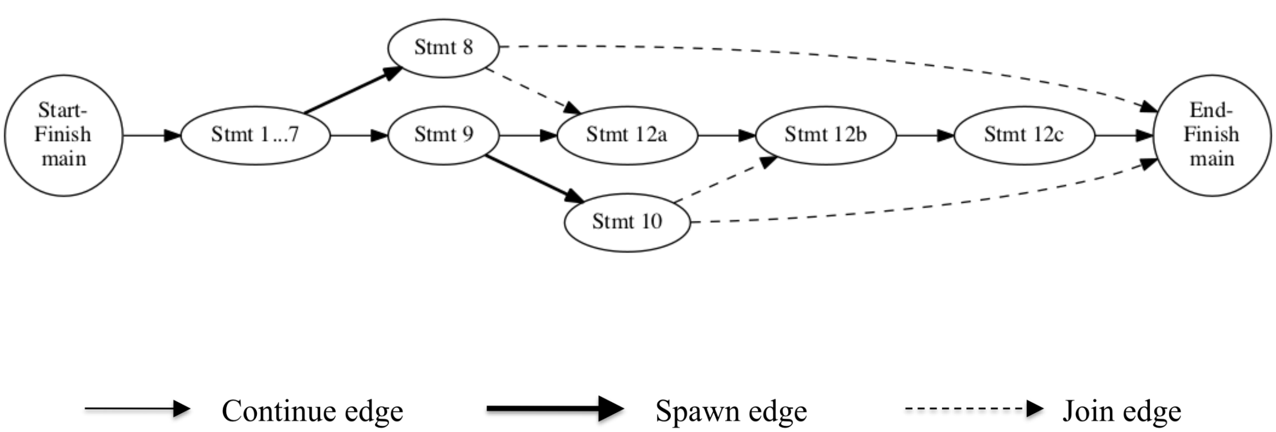
```
int sum = computeSum(X, 0, X.length-1); // main
static int computeSum(int[] X, int lo, int hi) {
  if ( lo > hi ) return 0;
  else if ( lo == hi ) return X[lo];
  else {
    final int mid = (lo+hi)/2;
    future<int> sum1 = async {
                         computeSum(X, lo, mid); };
    future<int>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

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



Computation graph of the program from Slide 10
when input array has length of 2