COMP 322: Fundamentals of Parallel Programming

Lecture 5: Futures — Tasks with Return Values

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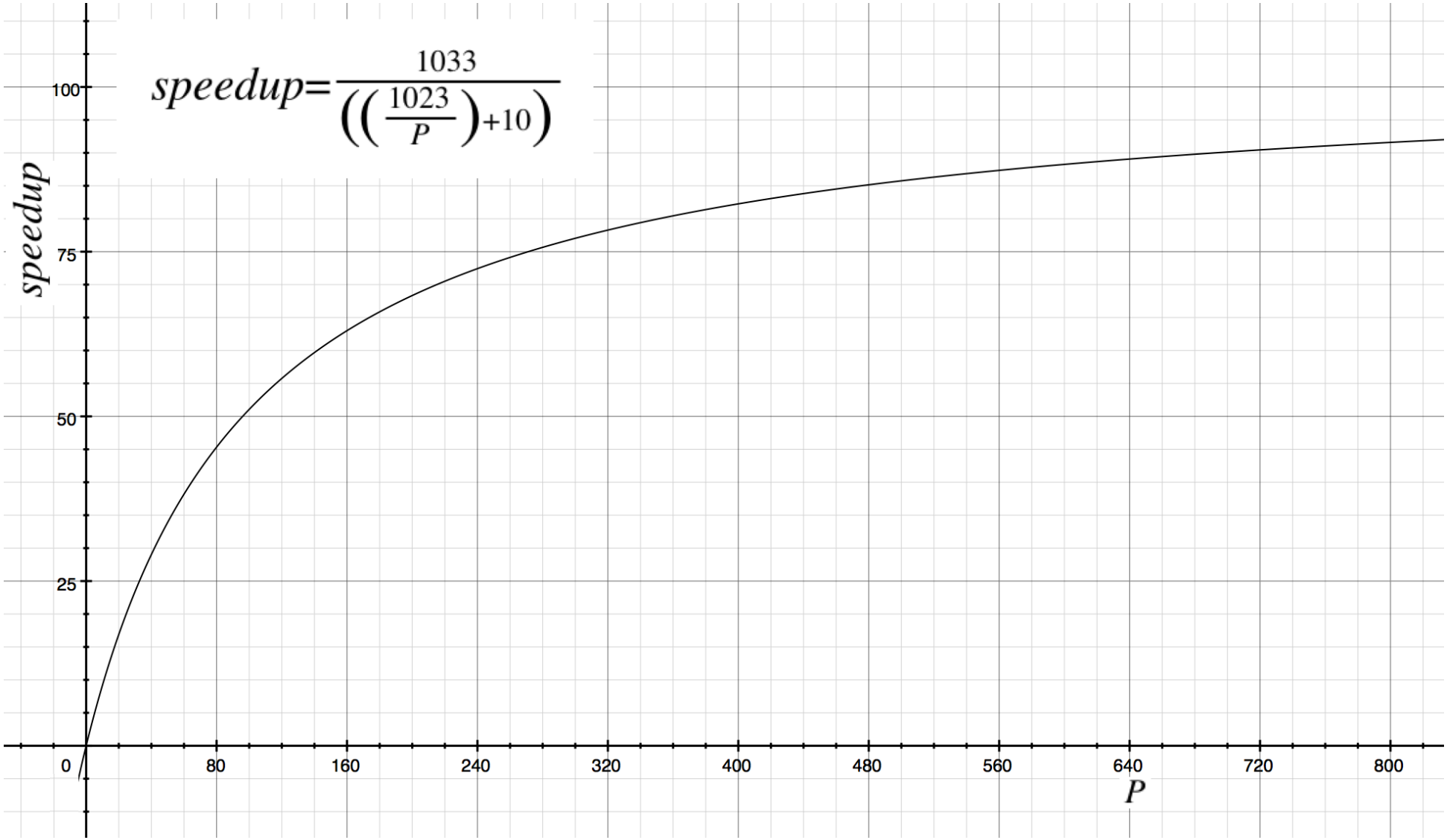
Solution to Worksheet 4

- 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

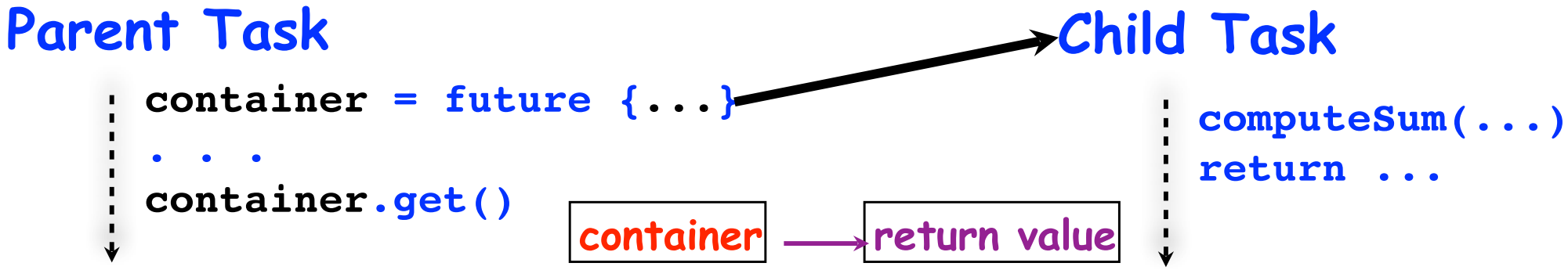
Example Scenario (PseudoCode)

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



HJ Futures: Tasks with Return Values

```
future<T> f =
    future { Stmt-Block }
```

- Creates a new child task to execute Stmt-Block, which returns a value of type T
- The future expression has type future<T>

```
Expr.get()
```

- Evaluate Expr, and block 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 future task

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

```
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();
```


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:

```
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.     // Parent now waits for the container values
12.     return sum1 + sum2;
13.   }
14. } // computeSum
```


Recursive Array Sum using Future Tasks

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.   }
14. } // computeSum
```


Computation Graph Extensions for Future Tasks

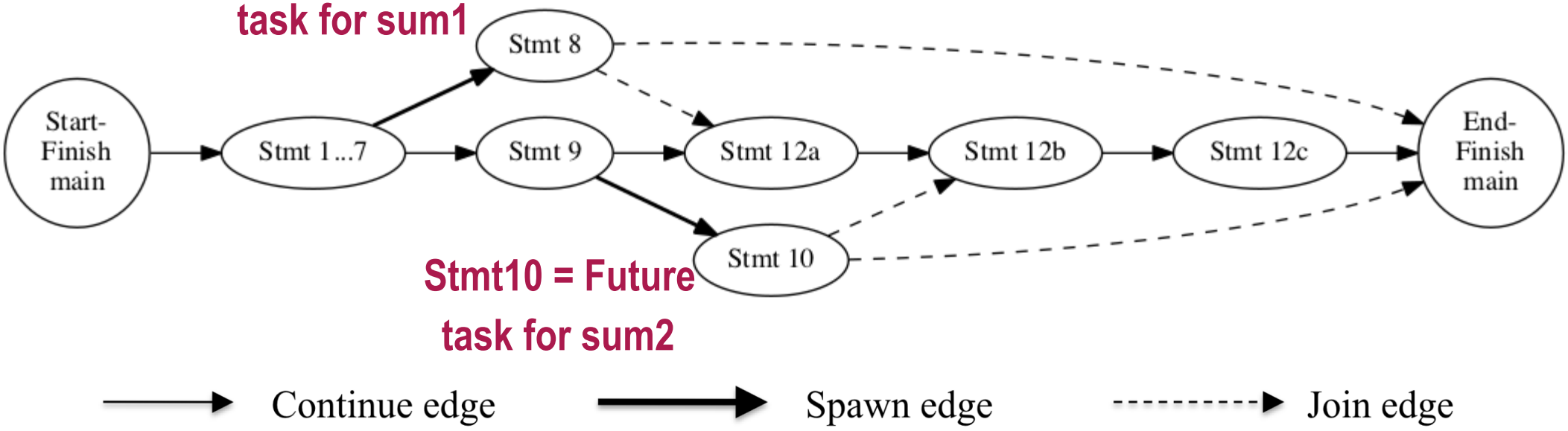
- Since a get() is a blocking operation, it must occur on boundaries of CG nodes/steps
  - —May require splitting a statement into sub-statements e.g.,
    - 12: `int sum = sum1.get() + sum2.get();`

      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

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

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

Stmt8 = Future task for sum1



Stmt10 = Future task for sum2

Continue edge Spawn edge Join edge

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

Announcements & Reminders

- **IMPORTANT:**
  - **—Watch video & read handout for topic 2.2 for next lecture on Monday, Jan 23rd**
- **HW1 was posted on the course web site (http://comp322.rice.edu) on Jan 11th, and is due on Jan 25th**
- **Quiz for Unit 1 (topics 1.1 - 1.5) is due by Jan 27th 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. Group office hours are now scheduled during 3pm - 4pm on MWF in DH 3092 (default room but alternate room may need to be used on some days — an announcement will be made in the lecture on those days)**