Lecture 15: Sequential Overheads from Task Granularity

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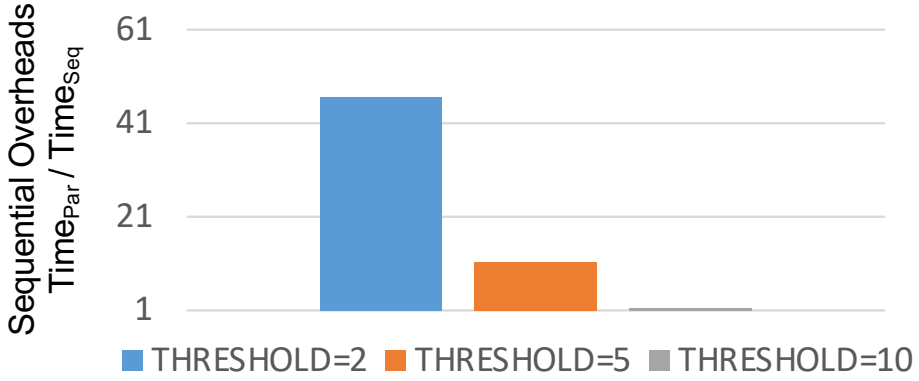
Today's Class

- Mid semester solution discussion
- Sequential overheads of work-stealing
  - Controlling task granularity

Sequential Overheads (1/2)

```
uint64_t fib(uint64_t n) {
  if (n < THRESHOLD) {
    return fib_sequential(n);
  } else {
    uint64_t x, y;
    finish([&]() {
      async([&x]() { x = fib(n-1); }
      async([&y]() { y = fib(n-2); }
    }
    return (x + y);
  }
}
```



- Sequential overhead = Ratio $Time_{seq}$ / $Time_{Par}$
  - $Time_{seq}$ is time for Fibonacci with serial elision
  - $Time_{seq}$ is for the corresponding parallel version, but by only using a single thread (sequential execution)
- **Observation**
  - Overheads can be controlled using **optimal task granularity**
    - Neither too many tasks, nor too few!
- Options to control task granularity?
  1. Calculate Task-2 (fib of n-2) sequentially
  2. Don't create async tasks when N is less than certain threshold
     - What threshold is optimal?
     - What depth in a recursion tree is optimal to execute sequentially?
  3. Use memoization
     - Saving and reusing previously computed values of a function rather than recomputing them

Running parallel recursive parallel Fib(40) using HClib as its async won't launch thread unlike std::async

Sequential Overheads (2/2)

- Creating an async is not same as executing it sequentially
  - Each async has some metadata associated with it
    - Recall, coping user lambda on heap is important so that it can be used later even if the function that created that task has gone out of scope
  - **It is important to control task granularity**
    - We will discuss three different solutions in this lecture

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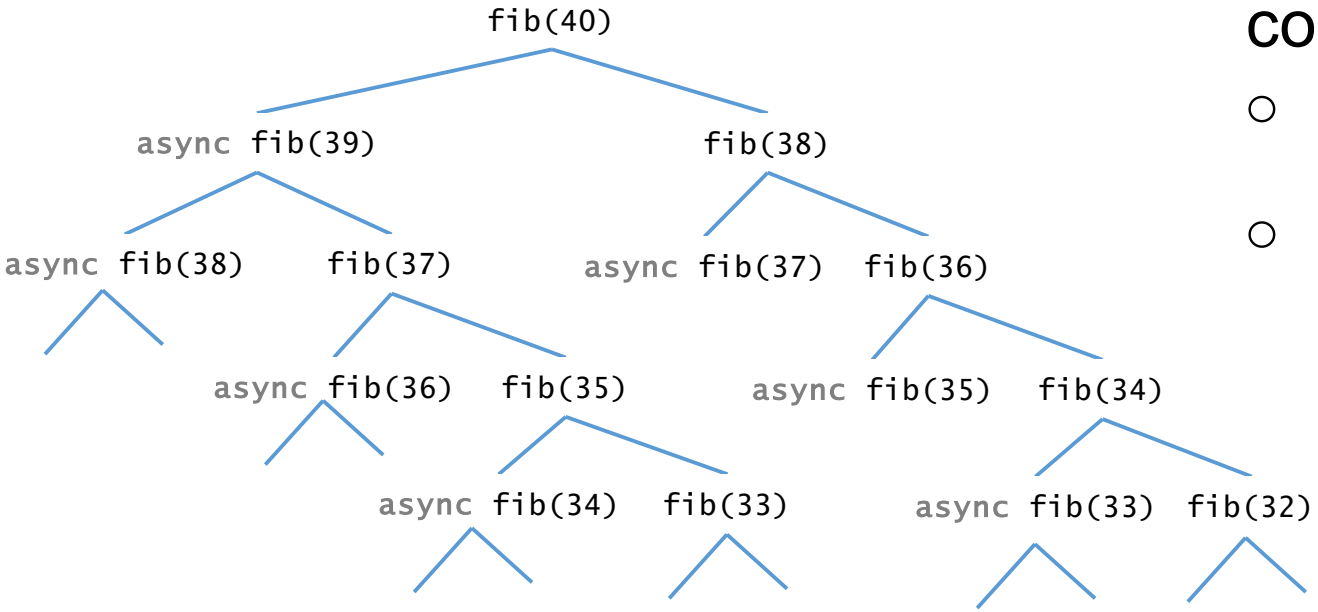
  - Controlling task granularity

First and Foremost, Work-Stealing is Best Suited for What Kind of Applications?



- Recursive divide-and-conquer style
  - Leads to fine granular task creation
  - How its helpful?
    1. Nested task creation

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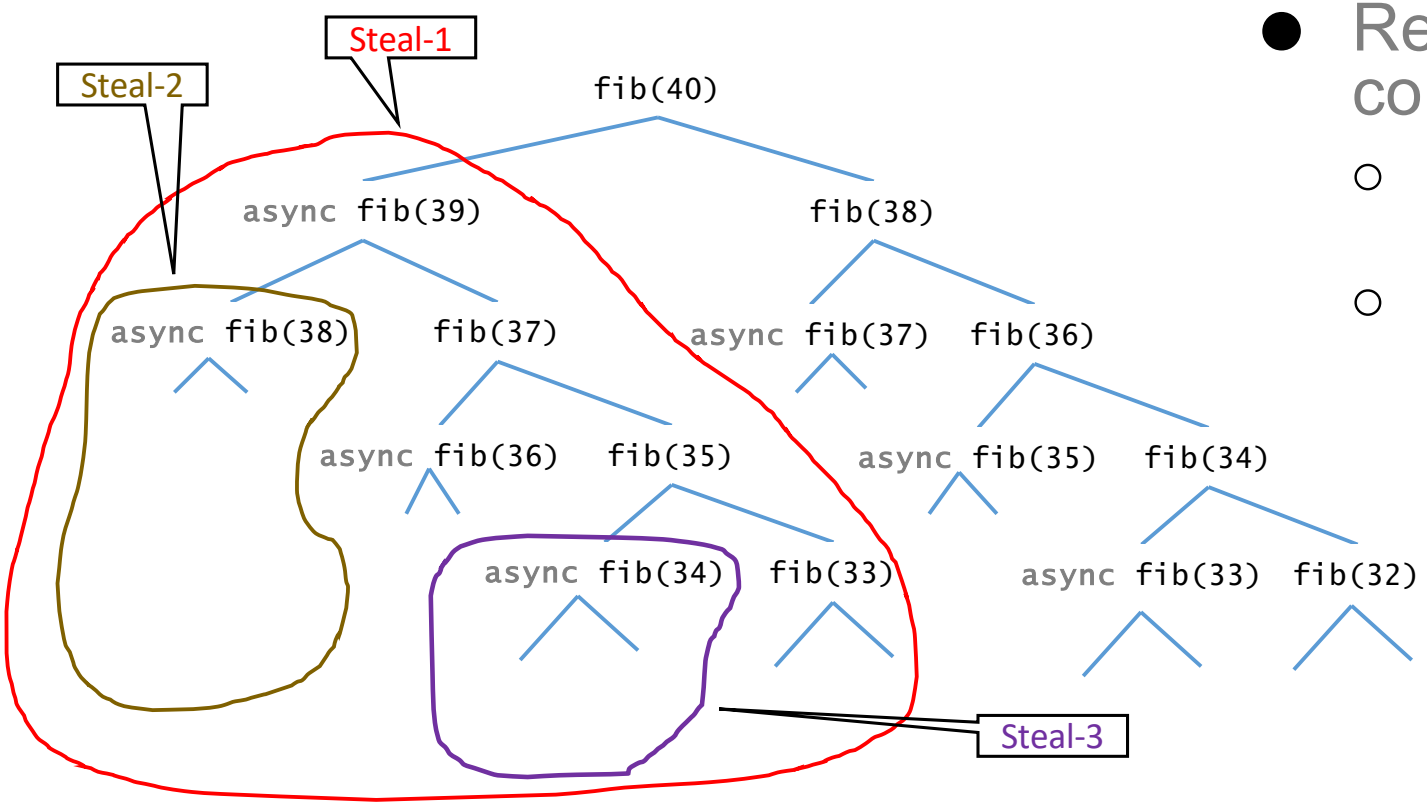
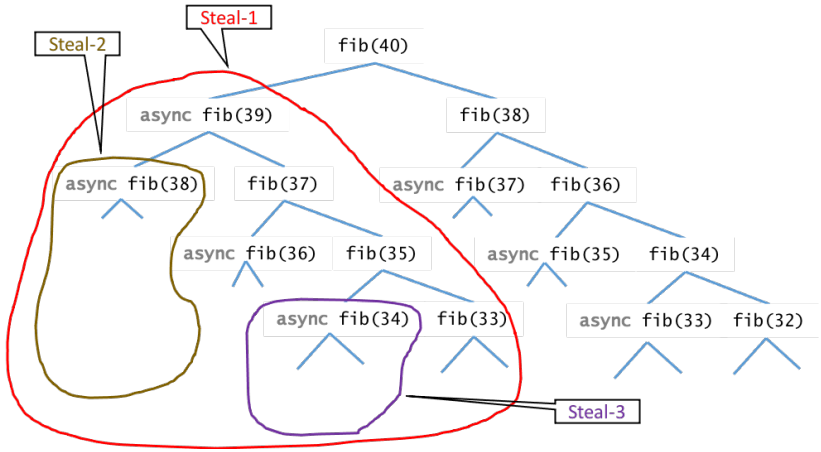
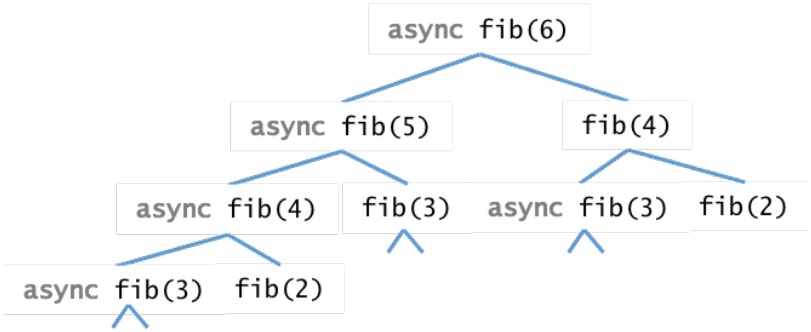


- Recursive divide-and-conquer style
  - Leads to fine granular task creation
  - How its helpful?
    1. Nested task creation
    2. Stealing an async will eventually give birth to several new asyncs at the thief
       - It will keep the thief busy and reduce steal attempts

First and Foremost, Work-Stealing is Best Suited for What Kind of Applications?





- Recursive divide-and-conquer style
  - Leads to fine granular task creation
  - **Disadvantages?**
    1. Tasks created near the bottom of the tree are too small in computation, and wouldn't be able to keep a thief busy once stolen

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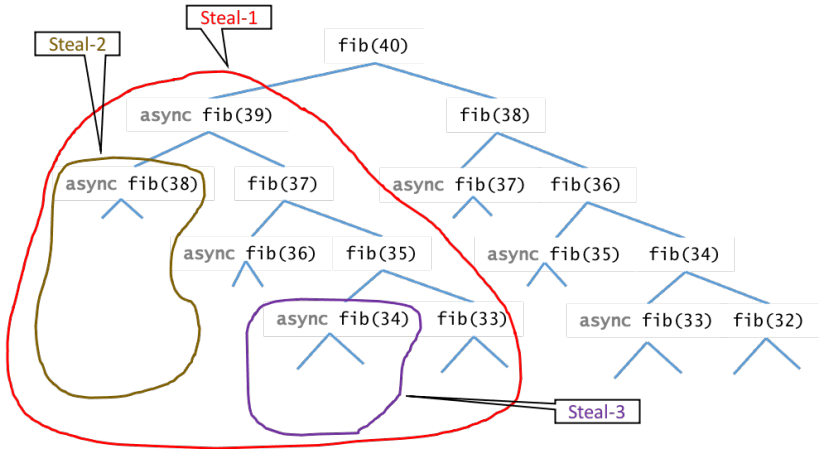
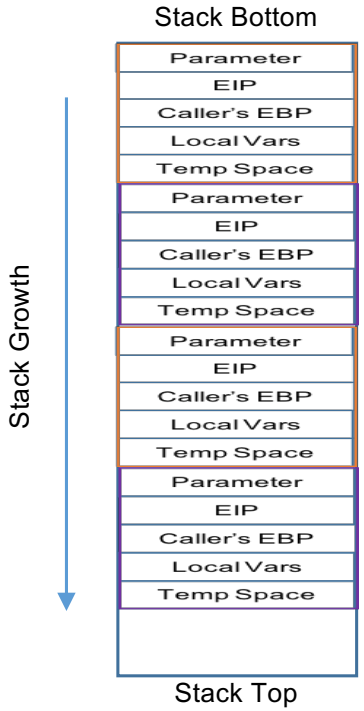




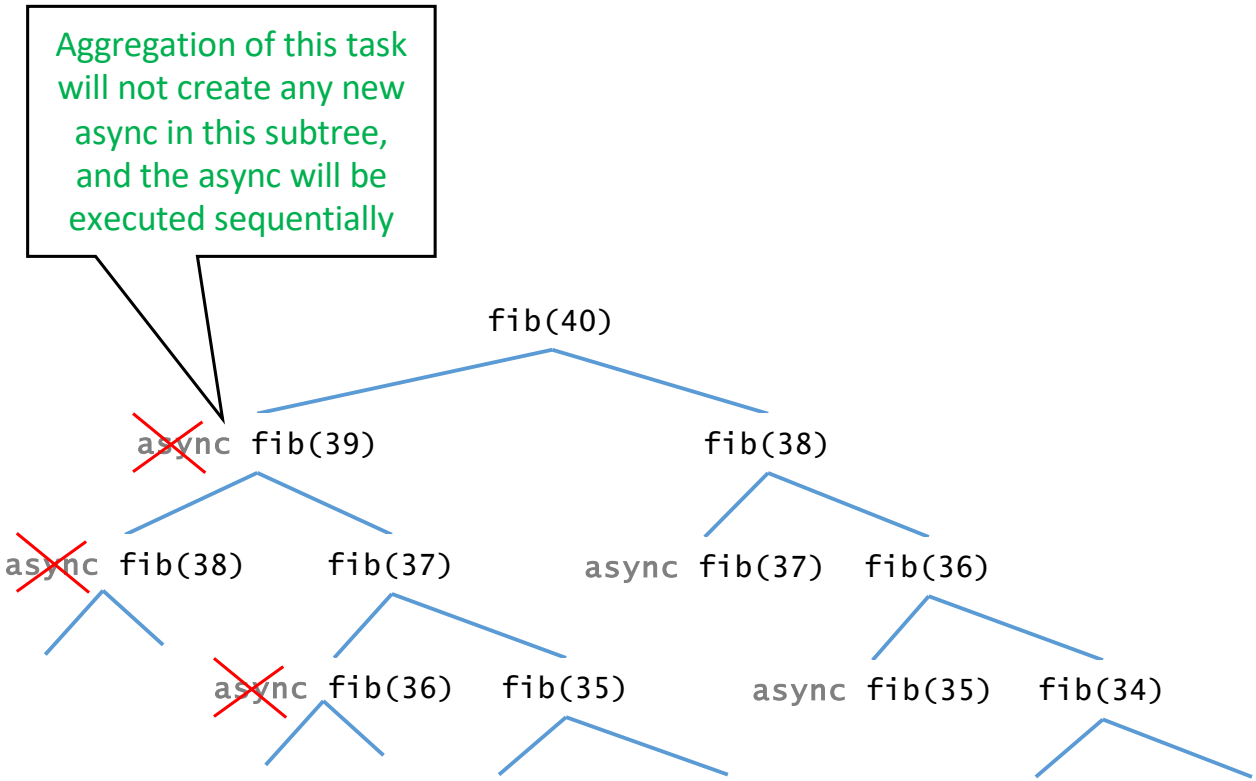
- Recursive divide-and-conquer style
  - Leads to fine granular task creation
  - **Disadvantages?**
    1. Tasks created near the bottom of the tree are too small in computation, and wouldn't be able to keep a thief busy once stolen
    2. Thread stack too deep
       - Too many context switches for moving back and forth between caller and callee stack frames (although in user space)

How to Avoid Sequential Overheads

1. Tasks near the bottom of the tree are small computations
   - Automatic granularity control
     - Stop creating new async after some "**depth**" is reached
     - Async created after that "depth" is executed sequentially

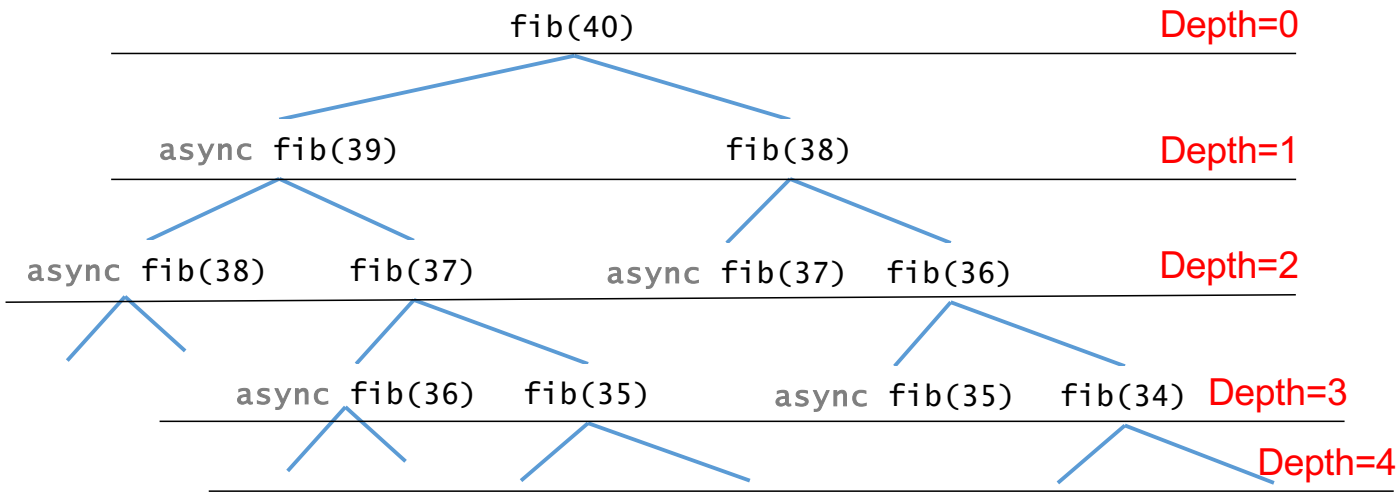
Solution-1: Automatic Granularity Control

- Runtime can perform dynamic task aggregations



Solution-1: Automatic Granularity Control

- Runtime can perform dynamic task aggregations
- Each task keeps track of its depth in the recursion tree, and its execution time
  - Depth is stored locally inside the task



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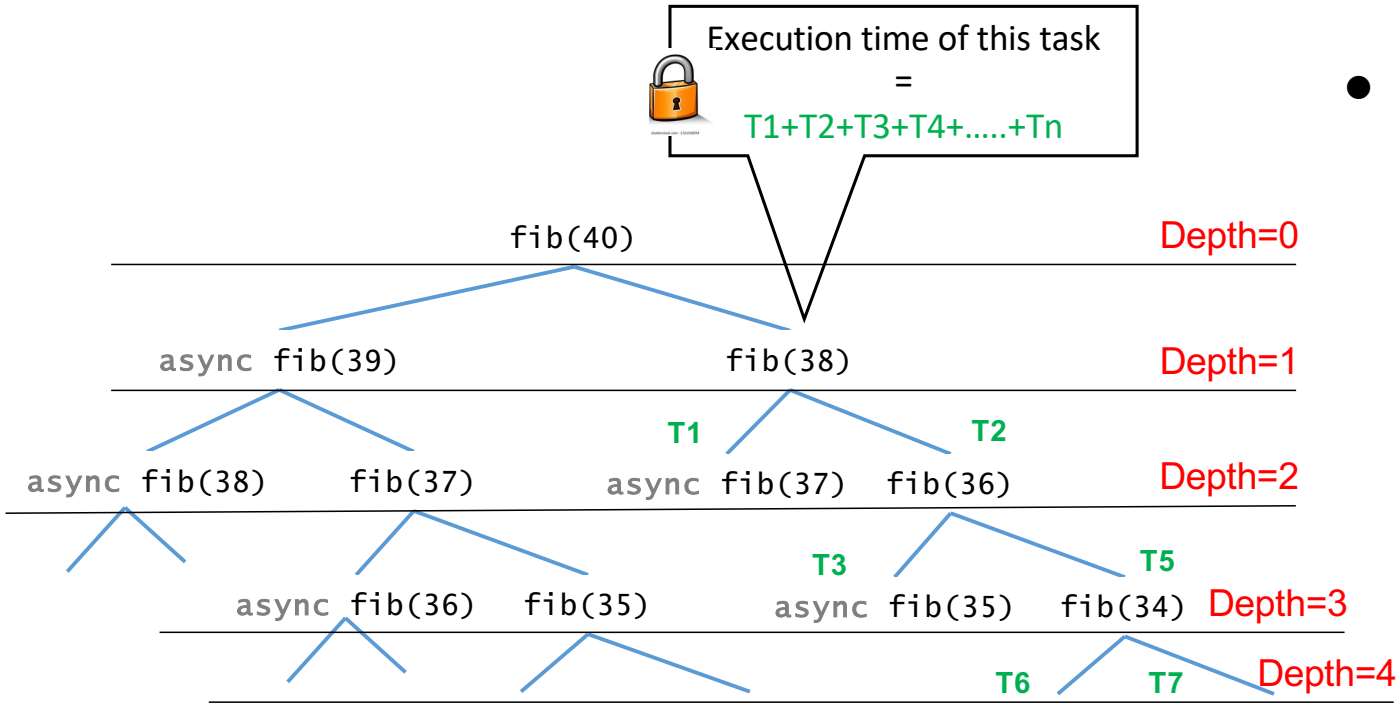

- Runtime can perform dynamic task aggregations
- Each task keeps track of its depth in the recursion tree, and its execution time
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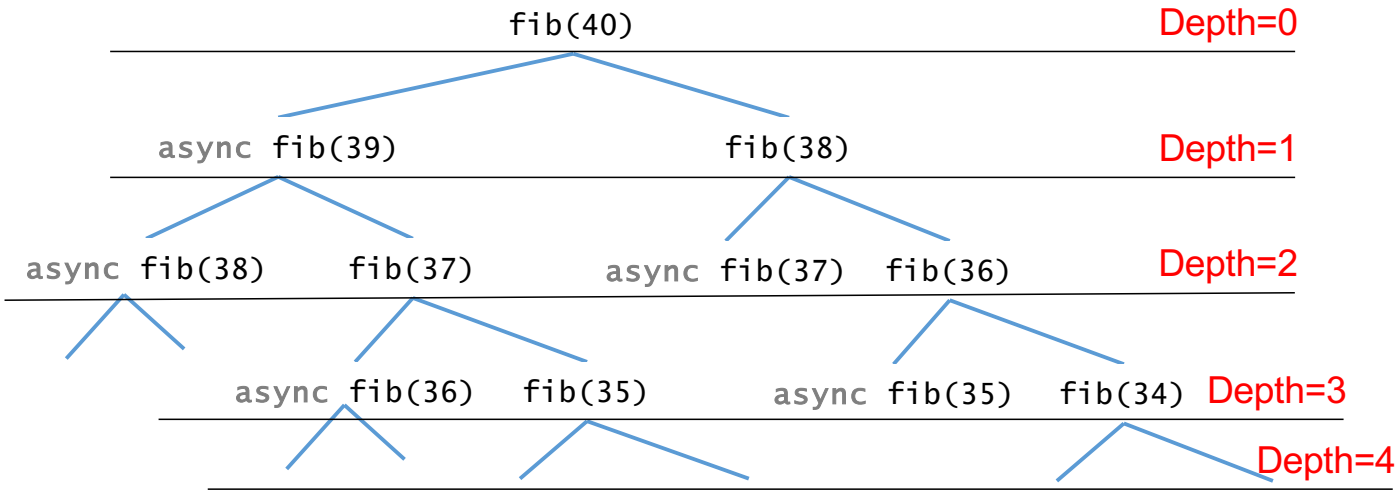
- Whenever a task complete its execution, it does two things
  - It add its execution time to the parent task's execution time
    - Mutual exclusion required

Solution-1: Automatic Granularity Control

Depth=0 Time=0	Depth=1 Time=0	Depth=2 Time=0	Depth=3 Time=0	



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  - Update the execution time at its depth in a shared global hash map (key=depth, value=time)

Solution-1: Automatic Granularity Control

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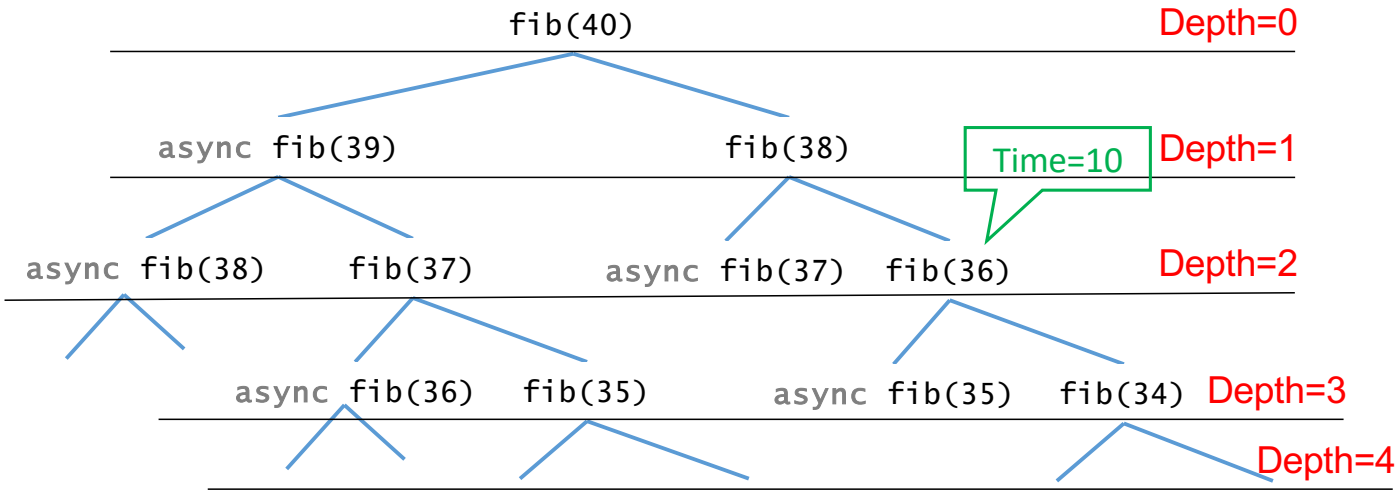

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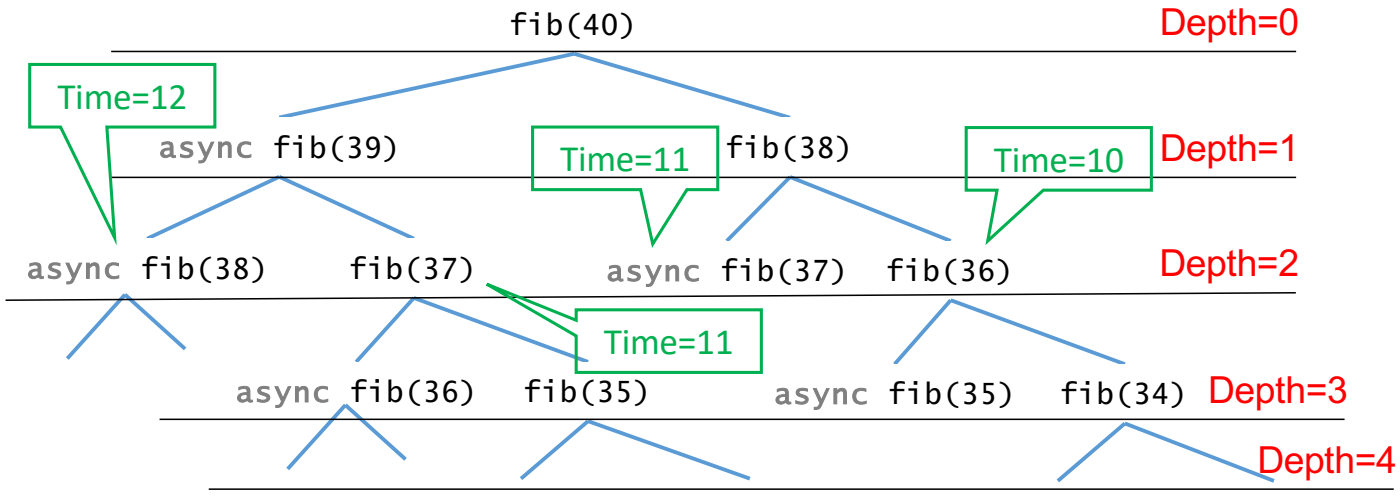

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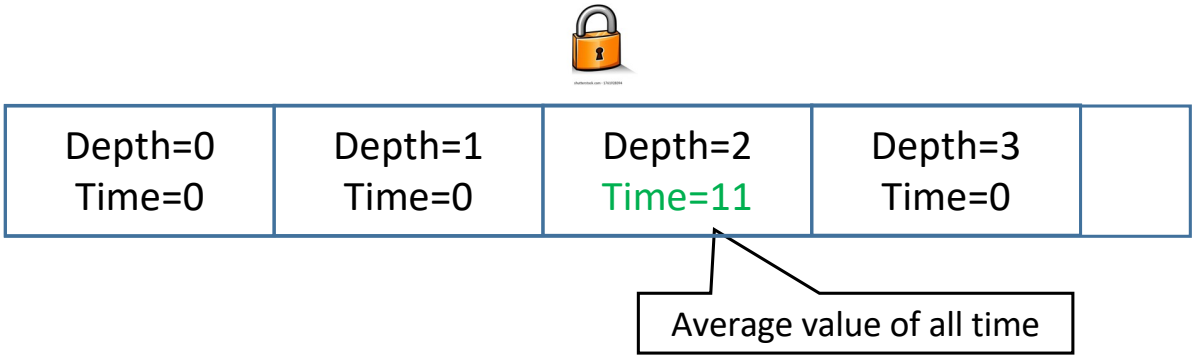
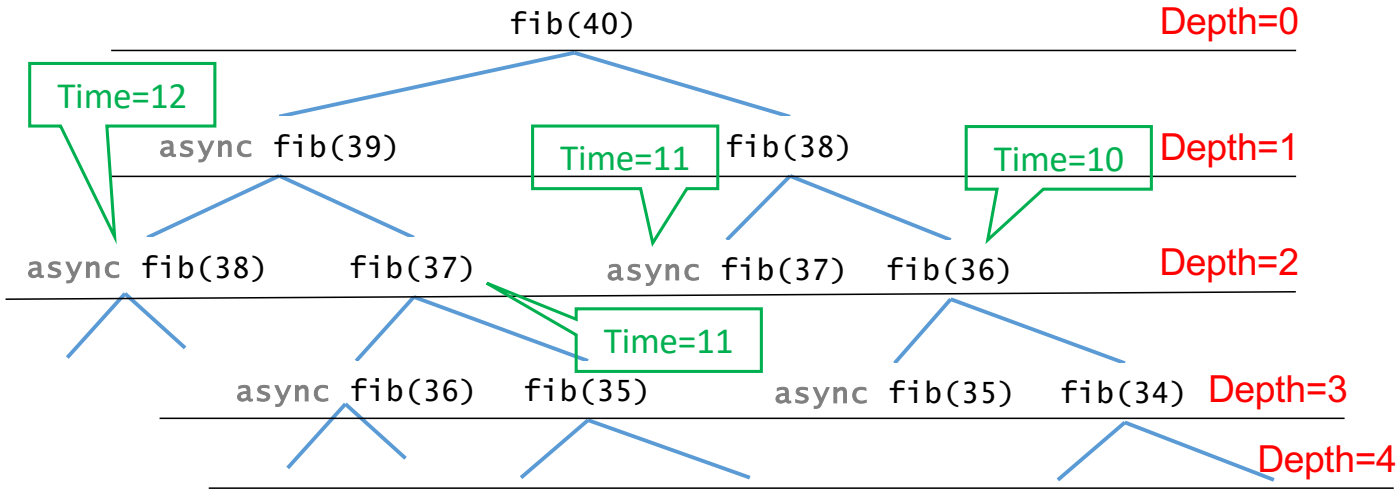
  - Update the execution time at its depth in a shared global hash map (key=depth, value=time)
    - Averaging of value (time) for a given key (depth) when more than one tasks complete its execution
    - Averaging would be stopped after enough samples collected at a depth

Solution-1: Automatic Granularity Control





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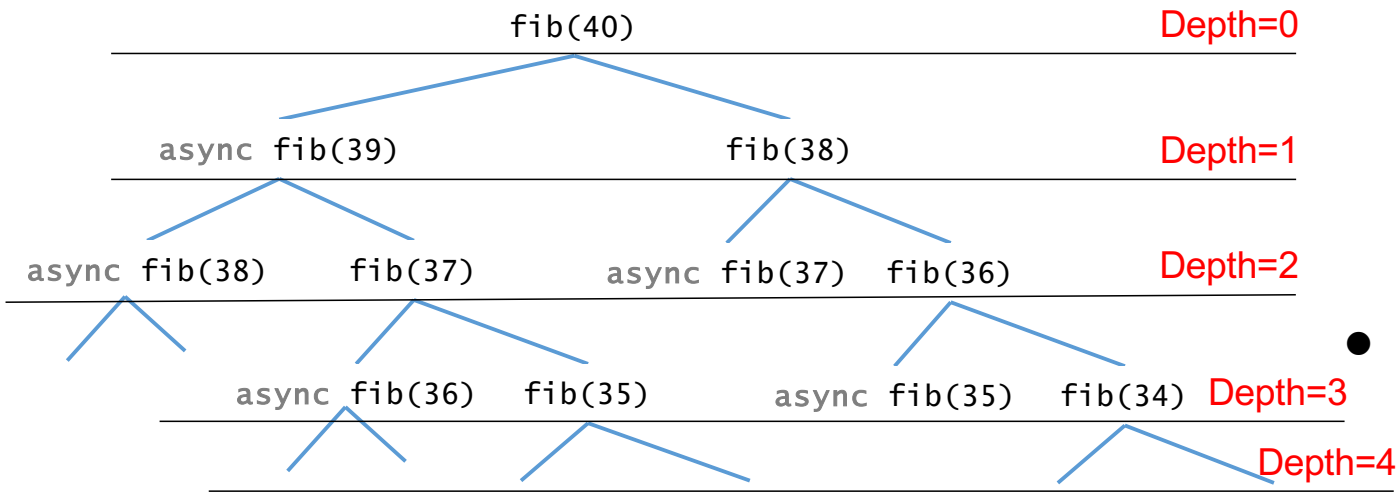
Solution-1: Automatic Granularity Control

Key=0 Value=14	Key=1 Value=12	Key=2 Value=11	Key=3 Value=9	



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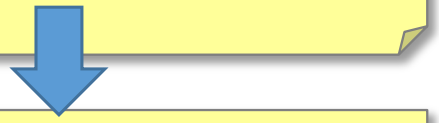
  - Update the execution time at its depth in a shared global hash map (key=depth, value=time)
    - Averaging of value (time) for a given key (depth) when more than one tasks complete its execution
    - Averaging would be stopped after enough samples collected at a depth
- Depth threshold decided based on the execution time of tasks at each depth
  - Beyond this depth threshold tasks would be aggregated

How to Avoid Sequential Overheads

1. Tasks near the bottom of the tree are small computations
   - Automatic granularity control
     - Stop creating new async after some "**depth**" is reached
     - Async created after that "depth" is executed sequentially
2. Deep thread stack due to recursion
   - Using two versions of the parallel code
     - Convert recursion into iterative call after appropriate "depth"

Solution-2: Using Two Versions of the Code

```
uint64_t fib(uint64_t n) {
  if (n < 2) {
    return n;
  } else {
    uint64_t x = fib(n-1);
    uint64_t y = fib(n-2);
    return (x + y);
  }
}
```



```
uint64_t fib(uint64_t n) {
  uint64_t f1=1;
  uint64_t f2=1;
  uint64_t m=2;
  while(m < n) {
    uint64_t temp = f2+f1;
    f1=f2;
    f2=temp;
    m=m+1;
  }
  return f2;
}
```

- When depth threshold is reached, switch to an iterative version of the recursive algorithm
  - Most of the recursive algorithms can be converted into iterative algorithm
  - Although, asking the user to provide an iterative version is breaking the support for serial elision

There is a general format for converting tail recursion into iterative version: https://www.baeldung.com/cs/convert-recursion-to-iteration

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   - Using two versions of the parallel code
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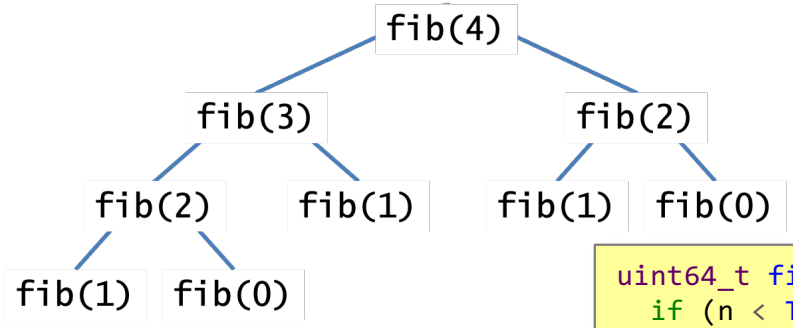
3. Memoization
   - Saving and reusing previously computed values of a function rather than recomputing them
   - An optimization technique with space-time tradeoff

Solution-3: Memoization

- Functional programming emphasizes functions whose results that depend only on their inputs and not on any other program state
- Revisiting recursive Fibonacci
  - Calling a function, fib(x), twice with the same value for the argument ‘x’ will produce the same result both times

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    }
    return (x + y);
  }
}
```

Solution-3: Applying Memoization on Fib (1/2)

```
uint64_t fib(uint64_t n) {
  int value = getValue(n);
  if(value != -1) return value;
  else if (n < 2) {
    return n;
  } else {
    uint64_t x, y;
    finish ([&]( ) {
      async ([&]( ){x = fib(n-1);});
      y = fib(n-2);
    });
    int result = x + y;
    storeValue(n, result);
    return result;
  }
}
```

```
My_hashmap<int, int> my_cache;
int getValue(int key) {
          /* return value if available */
          /* else return -1 */
}
void storeValue(int key, value) { ..... }
```

- A function can only be memoized if it is functional
- Related to caching
  - memoized function "remembers" the results corresponding to some set of specific inputs
  - memoized function populates its cache of results transparently on the fly, as needed, rather than in advance

Solution-3: Applying Memoization on Fib (2/2)

```
uint64_t fib(uint64_t n) {
  int value = getValue(n);
  if(value != -1) return value;
  else if (n < 2) {
    return n;
  } else {
    uint64_t x, y;
    finish ([&]( ) {
      async ([&]( ){x = fib(n-1);});
      y = fib(n-2);
    });
    int result = x + y;
    lock(); {storeValue(n, result);} unlock();
    return result;
  }
}
```

```
My_hashmap<int, int> my_cache;
int getValue(int key) {
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Reading Materials

- Automatic granularity control
  - An adaptive cut-off for task parallelism, SC 2008
    - https://www.academia.edu/download/35796885/1234120839604__a36-duran.pdf
- Using multiple versions of the code
  - A static cut-off for task parallel programs, PACT 2016
    - https://www.eidos.ic.i.u-tokyo.ac.jp/~iwasaki/files/PACT2016_slides.pdf
- You may only read the implementation section and skip theorem/proofs (if any)

Next Lecture

- Sequential overheads from concurrent deque