

# COMP 322: Parallel and Concurrent Programming

## Lecture 7: Futures

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# Lazy memo implementation (simplified)

```
public class Lazy<T> {
    private T contents;
    private Supplier<T> supplier;

    private Lazy(Supplier<T> supplier) {
        contents = null;
        this.supplier = supplier;
    }

    public T get() {
        if (contents != null) {
            return contents;
        }

        if (supplier != null) {
            contents = supplier.get();
            supplier = null;
        }

        return contents;
    }
}
```



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        if (supplier != null) {
            contents = supplier.get();
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    }
}
```

Private constructor (as usual) plus a factory method  
(*Lazy.of*)



# Lazy memo implementation (simplified)

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    private T contents;  
    private Supplier<T> supplier;  
  
    private Lazy(Supplier<T> supplier) {  
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    }  
  
    public T get() {  
        if (contents != null) {  
            return contents;  
        }  
  
        if (supplier != null) {  
            contents = supplier.get();  
            supplier = null;  
        }  
  
        return contents;  
    }  
}
```

If we've already computed the answer, return it.



# Lazy memo implementation (simplified)

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    private T contents;  
    private Supplier<T> supplier;  
  
    private Lazy(Supplier<T> supplier) {  
        contents = null;  
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    }  
  
    public T get() {  
        if (contents != null) {  
            return contents;  
        }  
  
        if (supplier != null) {  
            contents = supplier.get();  
            supplier = null;  
        }  
  
        return contents;  
    }  
}
```

Call the lambda (once), get the result, forget the lambda.



# Lazy memo implementation (simplified)

```
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        if (supplier != null) {
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        }

        return contents;
    }
}
```



# From laziness to parallelism

```
public class Lazy<T> {
    private T contents;
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    private Lazy(Supplier<T> supplier) {
        contents = null;
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    }

    public T get() {
        if (contents != null) {
            return contents;
        }

        if (supplier != null) {
            contents = supplier.get();
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        }

        return contents;
    }
}
```

Why lazy?

Maybe it's expensive to compute the *contents*

Maybe you won't actually need it

The idea: defer computation of a value until (and if) you need it.



# From laziness to parallelism

```
public class Lazy<T> {
    private T contents;
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    public T get() {
        if (contents != null) {
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        if (supplier != null) {
            contents = supplier.get();
            supplier = null;
        }

        return contents;
    }
}
```

Why lazy?

Maybe it's expensive to compute the *contents*

Maybe you won't actually need it

The idea: defer computation of a value until (and if) you need it.

What if?

I **know** that I **will** need the *contents* eventually

But **not right now**

My framework knows how to execute the *supplier* in parallel on spare resources, so I can go do something else in the meantime

The idea: offload the computation of the *contents* by the *supplier* to spare resources (another core), get the (hopefully already computed) value when you need it





# Futures

```
launchHabaneroApp(() -> {  
    var future = future(() -> { // Future task. Returns an HjFuture<String>  
        doRandomWork(1000, 2000);  
        System.out.println("Done with the future task");  
        return "Hello From the Future!";  
    });  
    doRandomWork(1500, 2500);  
    System.out.println("Done with the main task");  
    System.out.println("The future task returned the value " + future.get());  
});
```



# Futures

```
launchHabaneroApp(() -> {  
    var future = future(() -> { // Future task. Returns an HjFuture<String>  
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    });  
    doRandomWork(1500, 2500);  
    System.out.println("Done with the main task");  
    System.out.println("The future task returned the value " + future.get());  
});
```

Done with the main task

Done with the future task

The future task returned the value Hello From the Future!



# Futures

```
launchHabaneroApp(() -> {  
    var future = future(() -> { // Future task. Returns an HJFuture<String>  
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    System.out.println("Done with the main task");  
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});
```

Done with the main task  
Done with the future task  
The future task returned the value Hello From the Future!

Done with the future task  
Done with the main task  
The future task returned the value Hello From the Future!



# Futures

---

## Main program

```
var future = future(()->. . . )
```

```
doRandomWork(1500, 2500);
```

```
future.get()
```



# Futures



**Main program**

```
var future = future(()->. . . )
```

```
doRandomWork(1500, 2500);
```

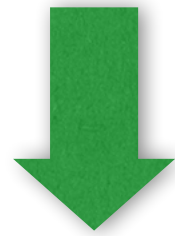
```
future.get()
```



# Futures

## Main program

**Empty**  
`var future = future(()->. .`



`doRandomWork(1500, 2500);`

`future.get()`

## Future task

`// Future task. Returns an HjFuture<String>  
( ) -> {`

`doRandomWork(1000, 2000);`

`return "Hello From the Future!";`

`}`



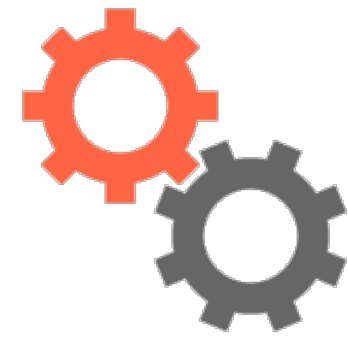
# Futures

## Main program

Empty

```
var future = future(()->. . . )
```

```
doRandomWork(1500, 2500);
```

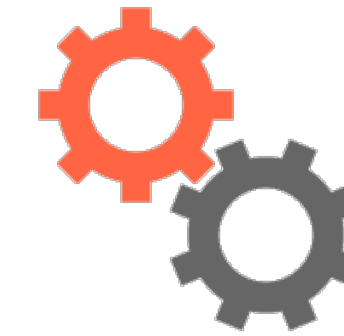


```
future.get()
```

## Future task

```
// Future task. Returns an HjFuture<String>  
( ) -> {
```

```
doRandomWork(1000, 2000);
```



```
return "Hello From the Future!";
```

```
}
```



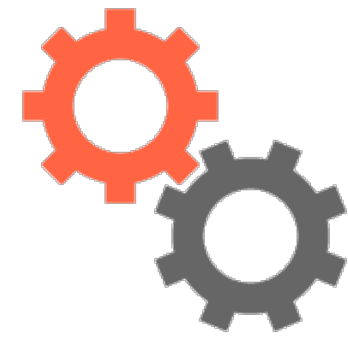
# Futures

## Main program

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var future = future(()->. . . )
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doRandomWork(1500, 2500);
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future.get()
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## Future task

```
// Future task. Returns an HjFuture<String>  
( ) -> {
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```
doRandomWork(1000, 2000);
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```
return "Hello From the Future!";
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```
}
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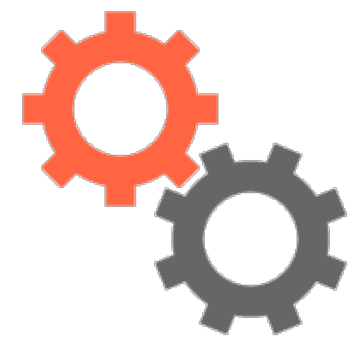


# Futures

## Main program

```
var future = future(()->. . . )
```

```
doRandomWork(1500, 2500);
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```
future.get()
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## Future task

```
// Future task. Returns an HjFuture<String>  
( ) -> {
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```
doRandomWork(1000, 2000);
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```
return "Hello From the Future!";
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}
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# Futures

## Main program

"Hello From the Future!"

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var future = future(()->. . . )
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```
doRandomWork(1500, 2500);
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```
future.get()
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## Future task

```
// Future task. Returns an HjFuture<String>  
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doRandomWork(1000, 2000);
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```
return "Hello From the Future!";
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```
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# Futures

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# Futures

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future.get()
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# Futures

## Main program

"Hello From the Future!"

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var future = future(()->. . . )
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```
doRandomWork(1500, 2500);
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```
future.get()  "Hello From the Future!"
```

## Future task

```
// Future task. Returns an HjFuture<String>  
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return "Hello From the Future!";
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# Futures

---

## Main program

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var future = future(()->. . . )
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# Futures



**Main program**

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doRandomWork(1500, 2500);
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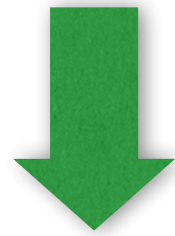


# Futures

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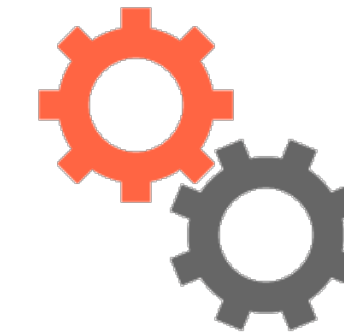


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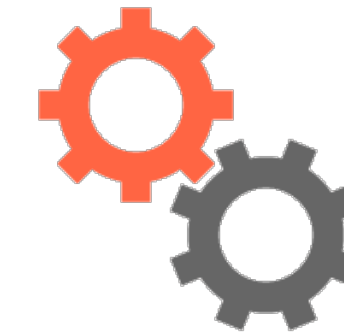


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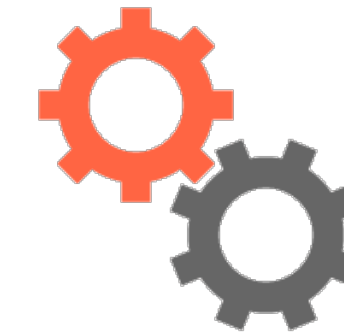
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# Futures

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# Futures

## Main program

"Hello From the Future!"

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future.get()
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## Future task

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// Future task. Returns an HjFuture<String>  
( ) -> {
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doRandomWork(1000, 2000);
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return "Hello From the Future!";
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# Futures

## Main program

"Hello From the Future!"

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var future = future(()->. . . )
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doRandomWork(1500, 2500);
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future.get()  "Hello From the Future!"
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## Future task

```
// Future task. Returns an HjFuture<String>  
( ) -> {
```

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doRandomWork(1000, 2000);
```

```
return "Hello From the Future!";
```

```
}
```



# What is a Future?

Read-only container (just like a Lazy Memo)

Always Empty on creation (just like a Lazy Memo)

Creation completes immediately (just like a Lazy Memo)

Gets computed and filled-in by a lambda (just like a Lazy Memo)

The user calls `get()` on it to get the value (just like a Lazy Memo)

The lambda to compute the value may be executed in parallel

- Unlike the Lazy Memo

The user may block on the first `get()` if the value is not ready

- **Kind of** like the Lazy Memo. The first `get()` on the Lazy Memo always (kind of) blocks: it has to wait for the lambda to execute.

Subsequent `get()` calls complete immediately (just like a Lazy Memo)





# Futures

Simple, but an extremely powerful concept in parallel and concurrent programming

Very functional in nature

Almost all languages and frameworks that have any kind of parallel and concurrent programming have them

**JavaScript** (Futures), **Kotlin** (asyncs), **Python** (futures in Ray on Python), **C++** (std::future), **Go** (closures and goroutines), **Scala** (futures), **C#** (Task<T>), **Clojure** (future), **Ruby** (Concurrent::Future), **R** (future package), **Swift** (Future)



# Example: Two-way parallel sum using Futures

```
// Parent Task T1 (main program)  
// Compute sum1 (lower half) & sum2 (upper half) in parallel  
var sum1 = future(() -> { // Future Task T2  
    int sum = 0;  
    for (int i = 0; i < X.length / 2; i++) sum += X[i];  
    return sum;  
});  
var sum2 = future(() -> { // 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();
```



# Another way of computing Parallel Sum

```
// Parent Task T1 (main program)
// Compute sum1 (lower half) & sum2 (upper half) in parallel

// Task T2 (the future task) computes the lower half sum
var sum1 = future(() -> { // Future Task T2
    int sum = 0;
    for (int i = 0; i < X.length / 2; i++) sum += X[i];
    return sum;
});

// Task T1 (the main program) computes the upper half sum
int sum2 = 0;
for (int i = X.length / 2; i < X.length; i++) sum2 += X[i];

// Task T1 waits for Task T2 to complete
int total = sum1.get() + sum2;
```



# Does this work?

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



# Recursive Array Sum (Sequential version)

## Sequential 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;
        int sum1 =
            computeSum(X, lo, mid);
        int sum2 =
            computeSum(X, mid+1, hi);

        return sum1 + sum2;
    }
} // computeSum

. . .

int sum = computeSum(X, 0, X.length-1); // main
```



# Recursive Array Sum (Future version)

Parallel divide-and-conquer pattern:

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

. . .

int sum = computeSum(X, 0, X.length-1); // main
```



# Summary

---

Futures are a highly functional, structured and disciplined way to express and coordinate concurrent execution

Simple, but powerful concept

Widespread in popular languages and frameworks

