Concurrent Programming Models

CS 475, Fall 2019
Concurrent & Distributed Systems

With material from Herlihy & Shavit, Art of Multiprocessor Programming
Barrier Synchronization
Barrier Synchronization
Barrier Synchronization

Until every thread has left here

No thread enters here
Combining Tree Barrier

• No sequential bottleneck
  – Parallel `getAndDecrement()` calls
• Low memory contention
  – Same reason
• Cache behavior
  – Local spinning on bus-based architecture
  – Not so good for non-uniform memory access architectures (NUMA) -
    common for large multiprocessor systems
So...How will we make use of multicores?

Back to Amdahl’s Law:

\[
\text{Speedup} = \frac{1}{(\text{ParallelPart}/N + \text{SequentialPart})}
\]

Pay for N = 8 cores
\[
\text{SequentialPart} = 25\%
\]

Speedup = only 2.9 times!

Must parallelize applications on a very fine grain!
Need Fine-Grained Locking

The reason we get only 2.9 speedup

25% Shared

75% Unshared

25% Shared

75% Unshared
Real-World Scaling Process

Parallelization and Synchronization will require great care…
Today

• How do we increase performance with parallelism?
• How do we split up our program into concurrent sections effectively?
• Different models for parallel computation
• Reading: H&S 16.1, 16.2
Designing for Performance

• What factors can impact performance?
  • Limits imposed by physics
  • Limits imposed by technology
  • Limits imposed by economics
• These limits can force us to make tradeoffs
  • Smaller chips are faster, but harder to dissipate heat
  • Need to serve X clients, can only spend Y on CPUs
Performance Metrics

• Capacity
  • Consistent measure of a service’s size or amount of resources
• Utilization
  • Percentage of that resource used for a workload
• Latency
  • How long it takes an input to propagate through a system and generate an output
• Throughput
  • Work done per time

Adjusted by buying more resources

Adjusted by thinking hard about the problem
Latency

- In client/server model, latency is simply: time between client sending request and receiving response
- What contributes to latency?
  - Latency sending the message
  - Latency processing the message
  - Latency sending the response
- Adding pipelined components -> latency is cumulative

Latency
Camera
Image Service
Sends images
10ns
Phase 1
Phase 2
5ns
10ns
5ns
Total latency: 30ns
Throughput

- Measure of the rate of useful work done for a given workload
- Example:
  - Throughput is camera frames processed/second
  - When adding multiple pipelined components -> throughput is the minimum value

![Image of Throughput Diagram]

- Camera sends images at 1000 fps.
- Image Service processes images:
  - Phase 1 processes at 10 fps.
  - Phase 2 processes at 29 fps.
- Total throughput: 10 fps.
Designing for Performance

• Measure system to find which aspect of performance is lacking (throughput or latency)
• Measure each component to identify bottleneck
• Identify if fixing that bottleneck will realistically improve system performance
• Measure improvement
• Repeat
Improving Throughput

Facebook.com Request

Cache Check → Build friends list → Build Newsfeed → Build Suggestions → Send response

Response
Improving Throughput

- Introduce concurrency into our pipeline
- Each stage runs in its own thread (or many threads, perhaps)
- If a stage completes its task, it can start processing the next request right away
- E.g. our system will process multiple requests at the same time
Reducing Latency

• Often more challenging than increasing throughput
  • Examples:
    • Physical - Speed of light (network transmissions over long distances)
    • Algorithmic - Looking up an item in a hash table is limited by hash function
    • Economic - Adding more RAM gets expensive
Latency & Stock Trading

• Buy low/sell high
• Most of skill is in knowing what a stock will do before your competitors
Latency & Stock Trading

• Algorithmic trading -> computer programs look at various factors, place trades automatically
• Example:
  • President Trump tweets positively about a company -> price goes up
  • Write a script to check twitter for company mentions, immediately buy/sell stock
  • Get in and out before it hits CNN!
Latency & Stock Trading

- This only works if you can make your trades **before** other people find out.
- What if you set up this bot in Chicago, and I set one up in NYC?
  - I would beat you to it, every time.
Latency & Stock Trading

- What is the speed of light?
  - ~300,000 km/sec
- How fast does your CPU execute an instruction?
  - 0.33 nanoseconds (say, 3Ghz CPU)
- How far does light travel in 1 CPU cycle?
  - 10 cm
- How many instructions does your CPU execute in the time it takes light to travel from Chicago to NYC and back?
  - ~700 miles -> 7.4msec -> 22 million instructions
- Being in NYC would let me execute 22 million instructions in the time it took you to send your stock order to NYC and get a response!
Reducing Latency with $$$$ 

- People actually care a LOT about the latency between NYC and Chicago, because commodities are traded in Chicago and stocks are traded in NYC.
- Changes to commodities prices (e.g. *ethanol*) can dramatically impact price of some stocks.
Reducing Latency with $$$$ 

- It’s not quite as simple as 700 miles -> 7.4msec
- There are streams, mountains, etc… more like 1,000 miles
- Light is refracted in a fiber optic cable is ~31% slower
- What do we do if money is no object?
Reducing Latency with Billions of Dollars

Reducing Latency without lots of $$$

- Approach: use **concurrency**
- Limited by serial section
Exploiting Concurrency

• These examples are at a very high level (components in a large server system)
• For this lecture, we’ll focus on smaller, more concrete examples
• First: Matrix Multiplication

\[
(C) = (A) \cdot (B)
\]
Matrix Multiplication

\[ c_{ij} = \sum_{k=0}^{N-1} a_{ki} \times b_{jk} \]
Matrix Multiplication

class Worker extends Thread {
    int row, col;
    Worker(int row, int col) {
        this.row = row; this.col = col;
    }
    public void run() {
        double dotProduct = 0.0;
        for (int i = 0; i < n; i++)
            dotProduct += a[row][i] * b[i][col];
        c[row][col] = dotProduct;
    }
}
Matrix Multiplication

class Worker extends Thread {
    int row, col;
    Worker(int row, int col) {
        this.row = row; this.col = col;
    }
    public void run() {
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Matrix Multiplication

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    }
    public void run() {
        double dotProduct = 0.0;
        for (int i = 0; i < n; i++)
            dotProduct += a[row][i] * b[i][col];
        c[row][col] = dotProduct;
    }
}

Which matrix entry to compute
Matrix Multiplication

class Worker extends Thread {
    int row, col;
    Worker(int row, int col) {
        this.row = row; this.col = col;
    }
    public void run() {
        double dotProduct = 0.0;
        for (int i = 0; i < n; i++)
            dotProduct += a[row][i] * b[i][col];
        c[row][col] = dotProduct;
    }
}
Matrix Multiplication

```java
void multiply() {
    Worker[][] worker = new Worker[n][n];
    for (int row = 0; row < n; row++)
        for (int col = 0; col < n; col++)
            worker[row][col] = new Worker(row,col);
    for (int row = 0; row < n; row++)
        for (int col = 0; col < n; col++)
            worker[row][col].start();
    for (int row = 0; row < n; row++)
        for (int col = 0; col < n; col++)
            worker[row][col].join();
}
```
Matrix Multiplication

```java
void multiply() {
    Worker[][] worker = new Worker[n][n];
    for (int row ...) {
        for (int col ...) {
            worker[row][col] = new Worker(row,col);
        }
    }
    for (int row ...) {
        for (int col ...) {
            worker[row][col].start();
        }
    }
    for (int row ...) {
        for (int col ...) {
            worker[row][col].join();
        }
    }
}
```
Matrix Multiplication

```java
void multiply() {
    Worker[][] worker = new Worker[n][n];
    for (int row ...){
        for (int col ...)
            worker[row][col] = new Worker(row, col);
        for (int row ...)
            for (int col ...)
                worker[row][col].start();
    for (int row ...)
        for (int col ...)
            worker[row][col].join();
}
```
Matrix Multiplication

```java
void multiply() {
    Worker[][] worker = new Worker[n][n];
    for (int row …) 
        for (int col …) 
            worker[row][col] = new Worker(row,col);
    for (int row …) 
        for (int col …) 
            worker[row][col].start();
    for (int row …) 
        for (int col …) 
            worker[row][col].join();
}
```

Start them

Wait for them to finish
Matrix Multiplication

```java
void multiply() {
    Worker[][] worker = new Worker[n][n];
    for (int row …)
        for (int col …)
            worker[row][col] = new Worker(row,col);
    for (int row …)
        for (int col …)
            worker[row][col].start();
    for (int row …)
        for (int col …)
            worker[row][col].join();
}
```
Thread Overhead

- Threads Require resources
  - Memory for stacks
  - Setup, teardown
- Scheduler overhead
- Worse for short-lived threads
Thread Pools

- More sensible to keep a pool of long-lived threads
- Threads assigned short-lived tasks
  - Runs the task
  - Rejoins pool
  - Waits for next assignment
Thread Pool = Abstraction

• Insulate programmer from platform
  - Big machine, big pool
  - And vice-versa

• Portable code
  - Runs well on any platform
  - No need to mix algorithm/platform concerns
ExecutorService Interface

- In java.util.concurrent
  - Task = Runnable object
    - If no result value expected
    - Calls run() method.
  - Task = Callable<T> object
    - If result value of type T expected
    - Calls T call() method.
    - Interesting question: how do you get the return value from call?
Callable<T> task = ...;
...
Future<T> future = executor.submit(task);
...
T value = future.get();
Submitting a Callable<T> task returns a Future<T> object

```java
Callable<T> task = ...;
...
Future<T> future = executor.submit(task);
...
T value = future.get();
```
Callable<T> task = ...;
...
Future<T> future = executor.submit(task);
...
T value = future.get();

The Future’s get() method blocks until the value is available
Future<?>

Runnable task = ...;
...
Future<?> future = executor.submit(task);
...
future.get();
Future<?>

Submitting a Runnable task returns a Future<?> object

Runnable task = ...;
...
Future<?> future = executor.submit(task);
...
future.get();
Runnable task = ...;
...
Future<?> future = executor.submit(task);
...
future.get();

The Future’s get() method blocks until the computation is complete
Note

• Executor Service submissions
  – Like Maryland traffic signs
  – Are purely advisory in nature

• The executor
  – Like the Maryland driver
  – Is free to ignore any such advice
  – And could execute tasks sequentially …
Matrix Addition

\[
\begin{pmatrix}
C_{00} & C_{00} \\
C_{10} & C_{10}
\end{pmatrix}
= 
\begin{pmatrix}
A_{00} + B_{00} & B_{01} + A_{01} \\
A_{10} + B_{10} & A_{11} + B_{11}
\end{pmatrix}
\]
Matrix Addition

\[
\begin{pmatrix}
C_{00} & C_{00} \\
C_{10} & C_{10}
\end{pmatrix}
= \begin{pmatrix}
A_{00} + B_{00} & B_{01} + A_{01} \\
A_{10} + B_{10} & A_{11} + B_{11}
\end{pmatrix}
\]

4 parallel additions
Matrix Addition Task

class AddTask implements Runnable {
    Matrix a, b; // multiply this!
    public void run() {
        if (a.dim == 1) {
            c[0][0] = a[0][0] + b[0][0]; // base case
        } else {
            (partition a, b into half-size matrices a_{ij} and b_{ij})
            Future<?> f_{00} = exec.submit(add(a_{00}, b_{00}));
            ...
            Future<?> f_{11} = exec.submit(add(a_{11}, b_{11}));
            f_{00}.get(); ...; f_{11}.get();
            ...
        }
    }
}
class AddTask implements Runnable {
    Matrix a, b; // multiply this!
    public void run() {
        if (a.dim == 1) {
            c[0][0] = a[0][0] + b[0][0]; // base case
        } else {
            (partition a, b into half-size matrices $a_{ij}$ and $b_{ij}$)
            Future<? extends void> f00 = exec.submit(add(a00,b00));
            ...
            Future<? extends void> f11 = exec.submit(add(a11,b11));
            f00.get(); ...; f11.get();
            ...
        }
    }
}

Base case: add directly
Matrix Addition Task

class AddTask implements Runnable {
    Matrix a, b; // multiply this!
    public void run() {
        if (a.dim == 1) {
            c[0][0] = a[0][0] + b[0][0]; // base case
        } else {
            // (partition a, b into half-size matrices a_{ij} and b_{ij})
            Future<?> f_{00} = exec.submit(add(a_{00}, b_{00}));
            ...
            Future<?> f_{11} = exec.submit(add(a_{11}, b_{11}));
            f_{00}.get(); ...
            f_{11}.get();
        }
    }
}
Matrix Addition Task

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    Matrix a, b; // multiply this!
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        } else {
            (partition a, b into half-size matrices a_{ij} and b_{ij})
            Future<?> f_{00} = exec.submit(add(a_{00},b_{00}));
            ...
            Future<?> f_{11} = exec.submit(add(a_{11},b_{11}));
            f_{00}.get(); ...; f_{11}.get();
            ...
        }
    }
}
Matrix Addition Task

class AddTask implements Runnable {
    Matrix a, b; // multiply this!
    public void run() {
        if (a.dim == 1) {
            c[0][0] = a[0][0] + b[0][0]; // base case
        } else {
            (partition a, b into half-size matrices a_{ij} and b_{ij})
            Future<?> f_{00} = exec.submit(add(a_{00},b_{00}));
            ...
            Future<?> f_{11} = exec.submit(add(a_{11},b_{11}));
            f_{00}.get(); ...; f_{11}.get();
            ...
        }
    }
}
Dependencies

• Matrix example is not typical
• Tasks are independent
  – Don’t need results of one task …
  – To complete another
• Often tasks are not independent
Fibonacci

• Note: potential parallelism, but subject to dependencies

\[
F(n) = \begin{cases} 
1 & \text{if } n = 0 \text{ or } 1 \\
F(n-1) + F(n-2) & \text{otherwise}
\end{cases}
\]
Disclaimer

- This Fibonacci implementation is
  - Egregiously inefficient
    - So don’t deploy it!
  - But illustrates our point
    - How to deal with dependencies
Multithreaded Fibonacci

class FibTask implements Callable<Integer> {
    static ExecutorService exec =
    Executors.newCachedThreadPool();
    int arg;
    public FibTask(int n) {
        arg = n;
    }
    public Integer call() {
        if (arg > 2) {
            Future<Integer> left  = exec.submit(new FibTask(arg-1));
            Future<Integer> right = exec.submit(new FibTask(arg-2));
            return left.get() + right.get();
        } else {
            return 1;
        }
    }
}
class FibTask implements Callable<Integer> {
    static ExecutorService exec = Executors.newCachedThreadPool();
    int arg;
    public FibTask(int n) {
        arg = n;
    }
    public Integer call() {
        if (arg > 2) {
            Future<Integer> left = exec.submit(new FibTask(arg-1));
            Future<Integer> right = exec.submit(new FibTask(arg-2));
            return left.get() + right.get();
        } else {
            return 1;
        }
    }
}
class FibTask implements Callable<Integer> {
    static ExecutorService exec = Executors.newCachedThreadPool();
    int arg;
    public FibTask(int n) {
        arg = n;
    }
    public Integer call() {
        if (arg > 2) {
            Future<Integer> left = exec.submit(new FibTask(arg-1));
            Future<Integer> right = exec.submit(new FibTask(arg-2));
            return left.get() + right.get();
        } else {
            return 1;
        }
    }
}
Dynamic Behavior

• Multithreaded program is
  - A directed acyclic graph (DAG)
  - That unfolds dynamically

• Each node is
  - A single unit of work
Fib DAG

Note inefficiency in this implementation: fib(2)’s result should be computed only once
Arrows Reflect Dependencies

Note inefficiency in this implementation: fib(2)’s result should be computed only once.
How Parallel is That?

• Define work:
  – Total time on one processor
• Define critical-path length:
  – Longest dependency path
  – Can’t beat that!
Fib Work
Fib Work

work is 17
Fib Critical Path

fib(4)

Graphical representation showing the critical path for calculating fib(4).
Fib Critical Path

Critical path length is 8
Notation Watch

- $T_P = \text{time on } P \text{ processors}$
- $T_1 = \text{work (time on 1 processor)}$
- $T_\infty = \text{critical path length (time on } \infty \text{ processors)}$
Simple Bounds

- $T_P \geq T_1/P$
  - In one step, can’t do more than $P$ work
- $T_P \geq T_\infty$
  - Can’t beat infinite resources
More Notation Watch

• Speedup on P processors
  – Ratio $T_1/T_P$
  – How much faster with P processors

• Linear speedup
  – $T_1/T_P = \Theta(P)$

• Max speedup (average parallelism)
  – $T_1/T_\infty$
Matrix Addition

$$\begin{pmatrix} C_{00} & C_{00} \\ C_{10} & C_{10} \end{pmatrix} = \begin{pmatrix} A_{00} + B_{00} & B_{01} + A_{01} \\ A_{10} + B_{10} & A_{11} + B_{11} \end{pmatrix}$$
Matrix Addition

\[
\begin{pmatrix}
C_{00} & C_{00} \\
C_{10} & C_{10}
\end{pmatrix}
= \begin{pmatrix}
A_{00} + B_{00} & B_{01} + A_{01} \\
A_{10} + B_{10} & A_{11} + B_{11}
\end{pmatrix}
\]

4 parallel additions
Addition

• Let $A_P(n)$ be running time
  - For $n \times n$ matrix
  - on $P$ processors
• For example
  - $A_1(n)$ is work
  - $A_\infty(n)$ is critical path length
Addition

- Work is

$$A_1(n) = 4A_1(n/2) + \Theta(1)$$

4 spawned additions

Partition, synch, etc
Addition

- Work is

\[ A_1(n) = 4 \ A_1(n/2) + \Theta(1) \]
\[ = \Theta(n^2) \]

Same as double-loop summation
Addition

- Critical Path length is

$$A_\infty(n) = A_\infty(n/2) + \Theta(1)$$

- Spawned additions in parallel
  - Partition, synch, etc
Addition

- Critical Path length is

\[ A_\infty(n) = A_\infty(n/2) + \Theta(1) = \Theta(\log n) \]
Matrix Multiplication Redux

\[(C) = (A) \cdot (B)\]
Matrix Multiplication Redux

\[
\begin{pmatrix}
C_{11} & C_{12} \\
C_{21} & C_{22}
\end{pmatrix} =
\begin{pmatrix}
A_{11} & A_{12} \\
A_{21} & A_{22}
\end{pmatrix} \cdot
\begin{pmatrix}
B_{11} & B_{12} \\
B_{21} & B_{22}
\end{pmatrix}
\]
First Phase ...

\[
\begin{pmatrix}
C_{11} & C_{12} \\
C_{21} & C_{22}
\end{pmatrix} = \begin{pmatrix}
A_{11} B_{11} + A_{12} B_{21} \\
A_{21} B_{11} + A_{22} B_{21}
\end{pmatrix} + \begin{pmatrix}
A_{11} B_{12} + A_{12} B_{22} \\
A_{21} B_{12} + A_{22} B_{22}
\end{pmatrix}
\]

8 multiplications
Second Phase ...

\[
\begin{pmatrix}
C_{11} & C_{12} \\
C_{21} & C_{22}
\end{pmatrix}
= 
\begin{pmatrix}
A_{11}B_{11} + A_{12}B_{21} & A_{11}B_{12} + A_{12}B_{22} \\
A_{21}B_{11} + A_{22}B_{21} & A_{21}B_{12} + A_{22}B_{22}
\end{pmatrix}
\]

4 additions
Multiplication

- Work is

\[ M_1(n) = 8 M_1(n/2) + A_1(n) \]

8 parallel multiplications

Final addition
Multiplication

- Work is

\[ M_1(n) = 8 \ M_1(n/2) + \Theta(n^2) \]
\[ = \Theta(n^3) \]

Same as serial triple-nested loop
Multiplication

- Critical path length is

\[ M_\infty(n) = M_\infty(n/2) + A_\infty(n) \]
Critical path length is

\[ M_\infty(n) = M_\infty(n/2) + A_\infty(n) = M_\infty(n/2) + \Theta(\log n) = \Theta(\log^2 n) \]
Parallelism

- $M_1(n)/M_\infty(n) = \Theta(n^3/\log^2 n)$
- To multiply two 1000 x 1000 matrices
  - $1000^3/10^2 = 10^7$
- Much more than number of processors on any real machine
Shared-Memory Multiprocessors

• Parallel applications
  - Do not have direct access to HW processors
• Mix of other jobs
  - All run together
  - Come & go dynamically
• Hence, we have **no control** over how many processors we get at any given point
• Instead, shoot for the best parallelism that we can get given however many processors we actually get
Back to the Future
Promises & CompleteableFutures

- What if we want to run some task, and do stuff while we are waiting for it to be done?
- You COULD do it with a complicated combination of synchronized, wait, and notify
- You can use the Promise abstraction instead
  - Called a CompletableFuture in Java 8
    CompletableFuture<String> future = CompletableFuture.supplyAsync(() -> {
      try {
        TimeUnit.SECONDS.sleep(1);
      } catch (InterruptedException e) {
        throw new IllegalStateException(e);
      }
      return "Result of the asynchronous computation";
    });
    // Block and get the result of the Future
    String result = future.get();
    System.out.println(result);
- Just like Future’s from before, but supports chaining
Chaining CompletableFuture

CompletableFuture<String> whatsYourNameFuture = CompletableFuture.supplyAsync(() -> {
    try {
        TimeUnit.SECONDS.sleep(1);
    } catch (InterruptedException e) {
        throw new IllegalStateException(e);
    }
    return "Jon";
});
// Chain on some more code to run when the future is done
CompletableFuture<String> greetingFuture = whatsYourNameFuture.thenApply(returnValue -> {
    return "Hello, " + returnValue;
});
System.out.println(greetingFuture.get()); // Hello Jon
Chaining CompletableFuture

```java
CompletableFuture<String> whatsYourNameFuture = CompletableFuture.supplyAsync(() -> {
    try {
        TimeUnit.SECONDS.sleep(1);
    } catch (InterruptedException e) {
        throw new IllegalStateException(e);
    }
    return "Jon";
});
// Chain on some more code to run when the future is done
CompletableFuture<String> greetingFuture = whatsYourNameFuture.thenApply(returnValue -> {
    return "Hello, " + returnValue;
});
System.out.println(greetingFuture.get()); // Hello Jon
```

Create an asynchronous task
Chaining CompletableFuture

```java
try {
    TimeUnit.SECONDS.sleep(1);
} catch (InterruptedException e) {
    throw new IllegalStateException(e);
}
return "Jon";
```

Task will return string “Jon” eventually

// Chain on some more code to run when the future is done
CompletableFuture<String> greetingFuture = whatsYourNameFuture.thenApply(returnValue -> {
    return "Hello, " + returnValue;
});
System.out.println(greetingFuture.get()); // Hello Jon
Chaining CompletableFuture

```
CompletableFuture<String> whatsYourNameFuture = CompletableFuture.supplyAsync(() -> {
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    }
    return "Jon";
});
// Chain on some more code to run when the future is done
CompletableFuture<String> greetingFuture = whatsYourNameFuture.thenApply(returnValue -> {
    return "Hello, " + returnValue;
});
System.out.println(greetingFuture.get()); // Hello Jon
```
Chaining CompletableFuture

```java
CompletableFuture<String> whatsYourNameFuture = CompletableFuture.supplyAsync(() -> {
    try {
        TimeUnit.SECONDS.sleep(1);
    } catch (InterruptedException e) {
        throw new IllegalStateException(e);
    }
    return "Jon";
});
// Chain on some more code to run when the future is done
CompletableFuture<String> greetingFuture = whatsYourNameFuture.thenApply(returnValue -> {
    return "Hello, " + returnValue;
});
System.out.println(greetingFuture.get()); // Hello Jon
```

Create ANOTHER future that is *chained* to the first
Chaining `CompletableFuture`

```java
CompletableFuture<String> whatsYourNameFuture = CompletableFuture.supplyAsync(() -> {
    try {
        TimeUnit.SECONDS.sleep(1);
    } catch (InterruptedException e) {
        throw new IllegalStateException(e);
    }
    return "Jon";
});

// Chain on some more code to run when the future is done
CompletableFuture<String> greetingFuture = whatsYourNameFuture.thenApply(returnValue -> {
    return "Hello, " + returnValue;
});
System.out.println(greetingFuture.get()); // Hello Jon
```

Block the main thread for both futures to finish

```java
); // Chain on some more code to run when the future is done
CompletableFuture<String> greetingFuture = whatsYourNameFuture.thenApply(returnValue -> {
    return "Hello, " + returnValue;
});
System.out.println(greetingFuture.get()); // Hello Jon
```
We can chain asynchronous activities together with the `thenAccept` term.

- Promise to get some data
  - Promise to make some other changes to that data
    - then
      - Promise to make some changes to that data
        - then
          - Report on those changes to the user
            - thenCombine
              - Report on the error
                - If there's an error...

- If there's an error...

CompleteableFuture Use-Cases

• Any case where you need to have multiple things happen in the background, but care about the result, and care about them happening in some order

• Asynchronous I/O
  • Read data from a web service
  • Then process it
  • Then save it to a file
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