COMP 322: Parallel and Concurrent Programming

Lecture 2: Functional Programming Basics

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What is Functional Programming?

- Programming Paradigm
- Treats programming as evaluating mathematical functions
- Avoids state
- Avoids mutation (no side effects)
- Recursion
- First-order functions
- Higher-order functions
- Closures
- Composition

Programming Paradigms

Functional Programming
- Evaluating mathematical functions
- Avoiding mutation
- Avoiding state
- Recursion, composition, higher-order functions

Object-Oriented Programming
- Data represented as objects
- Data manipulated through objects only
- Message passing
- Information hiding, abstraction, encapsulation
- Inheritance, Dynamic dispatch
- Imperative, procedural

Event-Driven Programming
- Control flow determined by events
- IO, GUI, interrupts, timers
- Event handlers
- Asynchronous processes

Declarative Programming
- Define program logic, but not control flow
- “What”, but not necessarily “how”
- Database queries, report generators

Programming Languages

- Java: Object-oriented, Functional, Event-driven
- C++: Object-oriented, Functional, Event-driven
- JavaScript: Event-driven, Functional, Object-oriented
- Python: Object-oriented, Functional
- SQL: Declarative
- Kotlin: Functional, Object-oriented, Event-driven
- Racket: Functional, Object-oriented
- Haskell: Functional
- Many, many others, mostly multi-paradigm

Why Functional Programming?

- Main focus: avoiding mutation of state
- A methodology for solving computation problems without mutating state
- State mutation is one of the biggest source of headaches and complexity in parallel and concurrent programming (more on this later in the course)
- Functional programming paradigm makes programs easier to design and manage when concurrency and parallelism are the goal
- FP is easier to think about before you start writing your code
- FP is easier to test and debug
  - Same inputs yield same outputs every time
- FP abstractions are much easier to run concurrently
- Not a silver bullet!

Thinking Functionally

- FP is a programming paradigm that feels like basic arithmetic
  - In no math class have you ever *mutated* a variable
  - Example: if you wrote $x = f(x)$ in a math class…
    - You'd be saying "x is a fixed point of f"
    - Not "overwrite the value of variable x with $f(x)$"
    - If you really needed to, you'd invent new variables, e.g.:

$$x_{n+1} = f(x_n) \implies x_n = f^n(x_0)$$

- **FP: Define things once, use them many times**

Simple example: Lists

```java
//
// Mutating lists
//
public class MList {
    public void push(Object o) { ... }
    public boolean contains(Object o) { ... }
    public Object pop() { ... }

    public boolean isEmpty() { ... }
}

MList ml = new MList();
ml.push("Hello");
ml.push("Rice");
ml.push("Owls");

System.out.println(ml.pop()); // Owls
System.out.println(ml.pop()); // Rice
System.out.println(ml.pop()); // Hello
```

```java
//
// Functional lists
//
public class ObjectList {
    public ObjectList prepend(Object o) { ... }
    public boolean contains(Object o) { ... }
    public Object head() { ... }
    public ObjectList tail() { ... }
    public boolean isEmpty() { ... }
}

ObjectList l = ObjectList.empty()
    .prepend("Hello")
    .prepend("Rice")
    .prepend("Owls");

System.out.println(l.head()); // Owls
System.out.println(l.tail().head()); // Rice
System.out.println(l.tail().tail().head()); // Hello
```

Better Idea: Generic Functional Lists

```
//
// Generic functional lists
//
interface GList<T> {
  GList<T> prepend(T o);
  boolean contains(T o);
  T head();
  GList<T> tail();
  boolean isEmpty();
  …

  static <T> GList<T> empty() { ... }
}

GList<String> list = GList.<String>empty()
    .prepend("Hello")
    .prepend("Rice")
    .prepend("Owls");

String s = list.head(); // no typecasting!
```

Two Kinds of Lists: A Cons and an Empty

```
/** Interface for a functional list over generic types. */
public interface GList<T> {
  // Data definition: a GList is one of two things:
  // - Cons: an element of type T, and another GList<T>
  // - Empty

 /** Returns the value of the first element in the list. */
  T head();

  /**
   * Returns a new list equal to the old list without its head() element. If the list is empty, this
   * will throw an exception.
   */
  GList<T> tail();
  . . .
  class Cons<T> implements GList<T> {
    private final T headVal;
    private final GList<T> tailVal;

    private Cons(T value, GList<T> tailList) {
      this.headVal = value;
      this.tailVal = tailList;
    }
    . . .
  }
  class Empty<T> implements GList<T> {
    . . .
 }
}
```

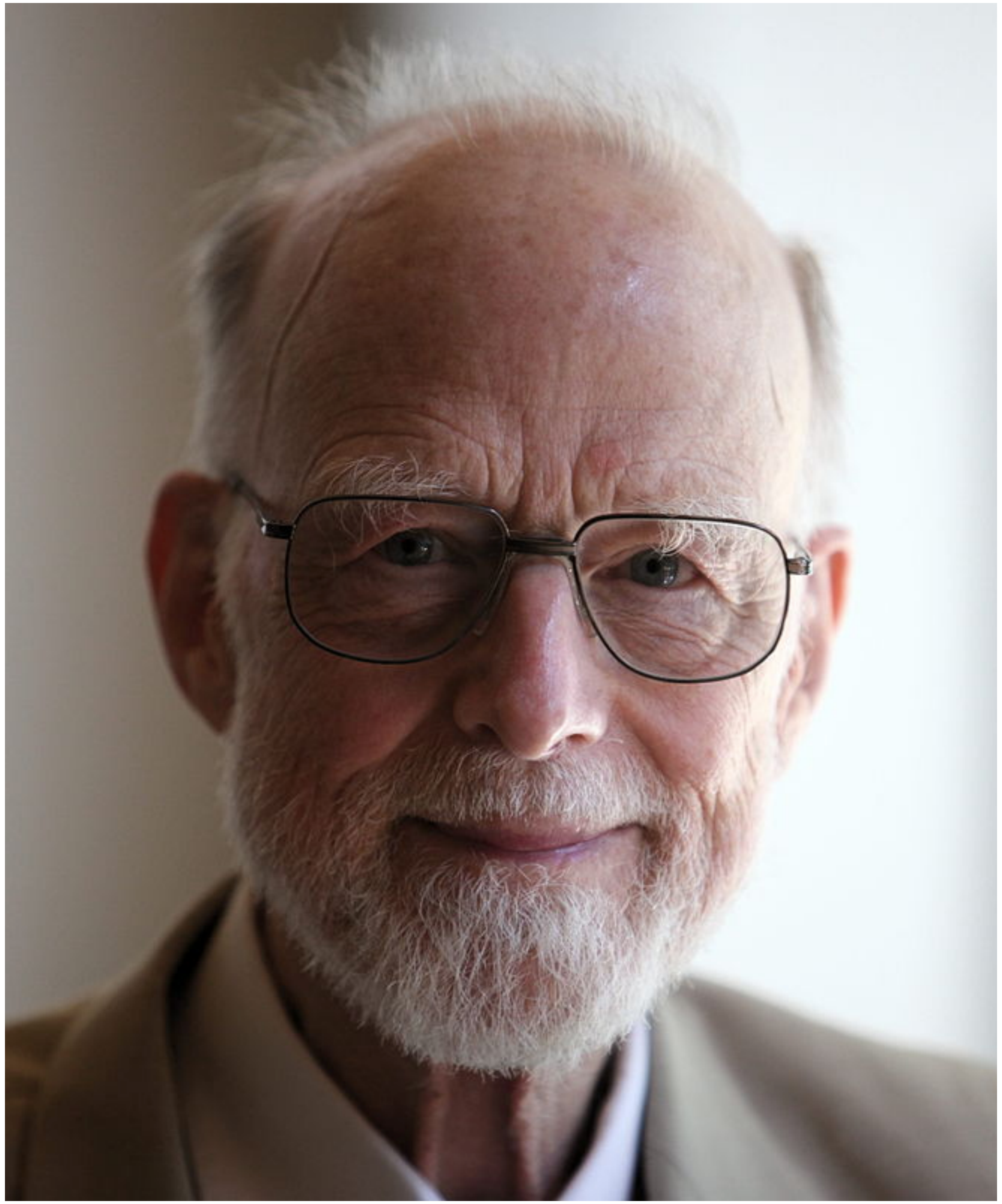
Why not just use ***null*** for an empty list?

Sir Tony Hoare on *null* references:

I call it my billion-dollar mistake. It was the invention of the null reference in 1965. At that time, I was designing the first comprehensive type system for references in an object oriented language (ALGOL W). My goal was to ensure that all use of references should be absolutely safe, with checking performed automatically by the compiler. But I couldn't resist the temptation to put in a null reference, simply because it was so easy to implement. This has led to innumerable errors, vulnerabilities, and system crashes, which have probably caused a billion dollars of pain and damage in the last forty years.

http://www.infoq.com/presentations/Null-References-The-Billion-Dollar-Mistake-Tony-Hoare

Java Practices: Avoid null if possible
http://www.javapractices.com/topic/TopicAction.do?Id=134



What's wrong with ***null***?

- Java (and many other languages) allows you to pass a ***null*** anywhere you would pass a reference to an object.
  - Super convenient when you want to represent a pointer to "nothing"
    - *Error conditions*: how should I return "nothing"?
    - *Uninitialized fields/members*: how should I represent "uninitialized"?
- You can't actually call a method on a ***null*** reference
  - *NullPointerException* at runtime, forces ***null*** checks everywhere.
  - Easy to forget, hard to debug.
- In general, avoid using ***null*** anywhere
- You can make IntelliJ warn you about it

There Should Be Only One Empty List!

```
interface GList<T> {

  //Create a new empty list of the given parameter type.
  @SuppressWarnings("unchecked")
  static <T> GList<T> empty() {
    return (GList<T>) Empty.SINGLETON;
  }



  class Empty<T> implements GList<T> {
    private Empty() { }

    private static final GList<?> SINGLETON = new Empty<>();
```

Why does this work? ***Type erasure!***

- Rule #1: there's only ever one "real" class (GList, etc.)
  - Java only uses type parameters at compile time, so `GList<String>` and `GList<Foo>` compile down to just `GList`
- **Implications**
  - At runtime, inside `GList<T>`, we don't know what T actually is
    - Forbidden: `T t = new T();`
  - There's only ever one static method / member of a given name

```
• private static final GList<?> SINGLETON = new Empty<>(); // original code
• private static final GList    SINGLETON = new Empty  (); // runtime, after type erasure
```

Why does this work? ***Type erasure!***

- Rule #1: there's only ever one "real" class (GList, etc.)
  - Java only uses type parameters at co
- **Implications**
  - At runtime, inside `GList<T>`, we do
    - Forbidden: `T t = new T();`
  - There's only ever one static method /
- `private static final GList<?>`
- `private static final GList`

Our empty-list never returns a **T**, so we'll get away with our "cheating".

```
public T head() {
  throw new NoSuchElementException("can't take head() of an empty list");
}
```

But there's no problem with returning `GList<T>`, since we get those from the `Cons` class.

```
public GList<T> prepend(T val) {
  return new Cons<>(val, this);
}
```

Related concept: *java.util.Optional<T>*

Container object

May or may not contain a non-null value

isPresent() tells us if the value is present in the container

get() returns the value if present, throws *NoSuchElementException* if not

MUCH better than using *null* to signal that “there is no answer”

Optional is just like a GList with exactly 0 or 1 elements

- Some languages (Haskell) actually implement it that way

Java type inference

- Q: Why don't we need to declare the type parameter of the Cons<>?

```
interface GList<T> {

  default GList<T> prepend(T val) {
    return new Cons<>(val, this);
  }
```

- A: Java figures it out from context.
  – IntelliJ will tell you if it can't make an inference.
    - You *must* declare type parameters for return types, argument types.
    - You *often* use a "diamond" <> for a constructor's type parameter.
    - You *often* leave out the type parameter (no diamond) for method calls.

More type inference

This code works:

```
GList<Integer> numbers =
    GList.<Integer>empty().prepend(1).prepend(2).prepend(3);
```

This code also works:

```
GList<Integer> emptyList = GList.empty();
GList<Integer> numbers = emptyList.prepend(1).prepend(2).prepend(3);
GList<Integer> numbers = GList.of(3, 2, 1);
```

This code won't compile:

```
GList<Integer> numbers = GList.<>empty().prepend(1).prepend(2).prepend(3);
```

This code won't compile, either:

```
GList<Integer> numbers = GList.empty().prepend(1).prepend(2).prepend(3);
```

More type inference

This code works:

```
GList<Integer> numbers =
    GList.<Integer>empty().pr
```

When in doubt, make yourself a separate empty-list of the correct type.

This code also works:

```
GList<Integer> emptyList = GList.empty();
GList<Integer> numbers = emptyList.prepend(1).prepend(2).prepend(3);
GList<Integer> numbers = GList.of(3, 2, 1);
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GList<Integer> numbers = GList.<>empty().prepend(1).prepend(2).prepend(3);
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This code won't compile, either:

```
GList<Integer> numbers = GList.empty().prepend(1).prepend(2).prepend(3);
```

New in Java10+: *var* declarations

This code works:

```
var numbers = GList.<Integer>empty().prepend(1).prepend(2).prepend(3);

var empty = GList.<Integer>empty();
var numbers = empty.prepend(1).prepend(2).prepend(3);
var numbers = GList.of(3, 2, 1);
```

This code doesn't work:

```
var empty = GList.empty();
var empty = GList.of();
var empty = GList.<>empty();
var numbers = GList.empty().prepend(1).prepend(2).prepend(3);
```

New in Java10+: ***var*** declarations

This code works:

```
var numbers = GList.<Integer>empty().prepend(1).prepend(2).prepend(3);

var empty = GList.<Integer>empty();
var numbers = empty.prepend(1).prepend(2).prepend(3);
var numbers = GList.of(3, 2, 1);
```

Java can't guess the type parameter

This code doesn't work:

```
var empty = GList.empty();
var empty = GList.of();
var empty = GList.<>empty();
var numbers = GList.empty().prepend(1).prepend(2).prepend(3);
```

var vs. explicit types

Great when it works!

But only works for local variables

```
public class Manufacturer {
  private final String name;
  private final String homepageUrl;

  private static final Map<String, Manufacturer> registry = new HashMap<>();

  static {
    for (var m : manufacturers) {
      registry.put(m.getName(), m);
    }
  }

  public static Manufacturer lookup(String name) {
    var result = registry.get(name);
    if (result == null) {
      throw new NoSuchElementException(name + " not present");
    } else {
      return result;
```

var vs. explicit types

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public class Manufacturer {
  private final String name;
  private final String homepageUrl;

  private static final Map<String, Manufacturer> registry = new HashMap<>();

  static {
    for (var m : manufacturers) {
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  }

  public static Manufacturer lookup(String name) {
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```

Local variables: **var** work great

var vs. explicit types

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      return result;
```

For-each variables: **var** work great

var vs. explicit types

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    for (var m : manufacturers) {
      registry.put(m.getName(), m);
    }
  }

  public static Manufacturer lookup(String name) {
    var result = registry.get(name);
    if (result == null) {
      throw new NoSuchElementException(name + " not present");
    } else {
      return result;
```

Member variables (static or instance): you still need explicit types

Recursion: list length

```
public interface GList<T> {

  class Cons<T> implements GList<T> {
    private final T headVal;
    private final GList<T> tailVal;

    public int length() {
     return 1 + tailVal.length();
   }
  }
  class Empty<T> implements GList<T> {
     public int length() {
       return 0;
     }
  }
}
```