Lesson 1

PROLOGUE

May 12, 2026

1. Administrivia
2. The Philosophy of Functional Programming
3. Types, Expressions, Values
4. Declarations
5. Closing Remarks

1 - Administrivia

I'm an alum who graduated four years ago[1] with a degree in computer science.

I TA'd 150 for seven semesters while I was at CMU, and I also taught this course three years ago, and then retired from teaching. It is a bad sign that I am back here now.

I currently work a full-time job as a software engineer at a security company called Semgrep, doing functional programming[2] for program analysis.

This means I am uniquely equipped as someone who works in the industry, to say that **functional programming is really useful**.

Note **I am not a professor**.

[1] Wow, time passes quick.

[2] Using a language very similar to the one you will learn in this class.

Brandon Wu

GHC 6008

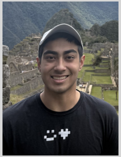
Alessandro

Andrew

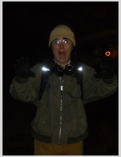
Angie

Arnim

Veer



Vincent



- Homework every week – due on Tuesdays or Thursdays (see the lecture schedule!)
- Quizzes most weeks on Fridays
- Turn in assignments via Gradescope
- Receive assignments via Canvas
- Piazza for any questions
- If you are not in all of { Gradescope, Piazza, Canvas } please let me know
- Slides, course policy, and other information at the course website here[3]

[3] As of May 12th, still under construction.

The full summer schedule can be found here (click me!)

The grading policy for this semester will follow a *choose-your-own-adventure* format.

There are two tracks of grades that we will support, the "Lecture Track" and the "Homework Track".

The Lecture Track is for students who would like to earn points via lecture attendance. Homework will count for 42% of the final grade, and lecture attendance will be 3%.

The Homework Track is for students who would rather not be graded for lecture attendance. Homework will instead count for 45%, and there will be no grading on lecture attendance.

Grading scheme selection will occur via Piazza after the first week.

(visualized via % of Farnam)

- Homework: 30%
- Lab Attendance: 10%
- Quizzes: 10%
- Midterm 1: 15%
- Midterm 2: 15%
- Final: 20%

(visualized via % of Farnam)

- Homework: 27%
- Lecture Attendance: 3%
- Lab Attendance: 10%
- Quizzes: 10%
- Midterm 1: 15%
- Midterm 2: 15%
- Final: 20%

One practice we are instituting this semester is **quizzes**.

Midterms are good for synchronously testing your understanding of the material, but they come too infrequently to be a good temperature check.

Quizzes this semester will be a more frequent assessment of your understanding, with lower stakes. The intention is that they should not be nearly at the difficulty of examination questions or homeworks, but be a good way to demonstrate your understanding of the material so we can know early if anyone is falling behind.

Fair game for quizzes is the **material covered in that week's lectures** and the **material graded in the previously due homework**. We will drop the lowest two quiz scores as well.

AI Policy

Our AI policy is simple: **No usage of AI is permitted**.

We will have more to say on this later. Suffice to say that you are at a stage of your education where you are not yet ready to use AI in a way that can help you learn.

Please make maximal use of the humans that are being paid minimum wage (and me) to help you, whether through Piazza or office hours.

Your health is important.

The things you will learn in this class are important, but remember that **it's just a class**. If you're sleeping 4 hours a night, skipping meals, or otherwise compromising your health for the sake of this class, **something is wrong**.

Things that are required:

- Sleeping
- Eating
- Socializing (for most people)
- Paying taxes

Things that are not required:

- Finishing 150 homework at the expense of these four things[4]

[4] Especially the last one.

Take care of yourself, and if you're experiencing difficulties, don't hesitate to reach out to myself or a TA you trust. For more severe cases, please go to `http://www.cmu.edu/counseling/`

My job is to teach you, not to ruin your life. If you're struggling, **talk to me**. Let's make a plan to help you succeed.

Slido code: #3951 716

Go to slido.com to ask anonymously!

2 - The Philosophy of Functional Programming

What is functional programming?

Well, hold up. What is programming?

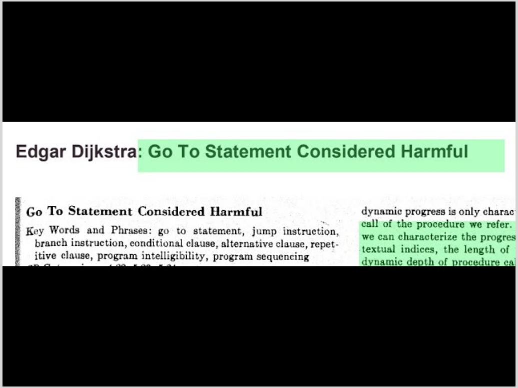
Programming is the act of **instructing a computer on how to achieve some kind of operation.**

Programming is **inherently a communicative act.**

Instructing is the key word. Good communication exists, so what is good programming?

Functional programming is **an improvement on our ability to communicate as programmers**.

Good code should allow you to **reason without running**.


Edgar Dijkstra: Go To Statement Considered Harmful

Go To Statement Considered Harmful

Key Words and Phrases: go to statement, jump instruction, branch instruction, conditional clause, alternative clause, repetitive clause, program intelligibility, program sequencing

dynamic progress is only charac
call of the procedure we refer.
we can characterize the progres
textual indices, the length of
dynamic depth of procedure cal

```
template <typename T>
void goto_sort( T array[], size_t n ) {
        size_t i{1}

        first: T current{array[i]};
        size_t j{i};

        second: if ( array[j - 1] <= current ) {
                goto third;
        }

        array[j] = array[j - 1];

        if ( --j ) {
                goto second;
        }

        third: array[j] = current;

        if ( ++i != n ) {
                goto first;
        }
}
```

Good code should allow you to **reuse without rewriting**.

Logically distinct parts should be *modular*, for separate maintenance and reuse.

You should be able to think about a single area of a codebase without needing to concern yourself with unrelated logic.

Good code should let you **change without breaking**.

Programs should be written with future maintainability in mind.

This goes hand-in-hand with descriptivity and modularity, but code which is written expressively, and has future expansion in mind, will be easiest to maintain.

Let's look at an example of non-functional code in Python.

```
count = 0

def increment():
  global count
  count += 1

  return count
```

What does `increment()` return?

The answer: **it depends**. On the first call, it returns `1`, and on the second call, `2`, and so on.

This demonstrates what we call **state**.

Suppose you are a master chef at a 5-star restaurant.

An imperative program is like a fully crowded kitchen with no rules.

- Everyone uses the same ingredients and the same cookware.
- **Each cook is an individual actor that can mess with the others**, if care is not taken. The health of the kitchen depends on each individual chef.

A functional program is like a kitchen where each cook has their own working space.

- Everyone has their own pots, pans, and ingredients, and they only share things when they finish producing their individual parts.
- **Each cook only interacts when sharing finished results**. This means it is impossible for one cook's actions to mess up another's cooking.

Programming, Imperatively

Computation by **modifying the computer's state**

```
x := 2;
x + x
```

Programming, Functionally

Computation by **reduction of expressions to values**

```
2 + 2
```

In stateful programs, we use commands like `x := 2` to *change the world*, to be one where `x + x` is 4.

This doesn't stop another part of the program from changing that later!

In functional programs, we apply simplifying rules to expressions like `2 + 2`, to obtain the value of `4`.

These expressions are **disjoint**, in that evaluation of one expression is unrelated to the evaluation of another.

Key In stateful programs, understanding a program entails not only understanding what the code does, but knowing the **entire history of the program up until that point.**

Functional programming **avoids modification of state**.

Def A function is *pure* if it does not have any observable side effects, and always returns the same outputs, given the same inputs.

A large amount of problems in computer science are of a pure nature. This means that they give the same outputs for the same inputs. (For example, finding the shortest path through a graph, computing the nth prime number, or compressing a file)

An important motivation behind functional programming will end up being that we should prefer to solve pure problems with pure components. In other words, don't introduce state when it's not necessary!

Functional programming can be characterized by three theses, which will be a recurring theme throughout the semester.

1. Recursive Problems, Recursive Solutions
2. Programmatic Thinking is Mathematical Thinking
3. Types Guide Structure

In this class, **almost every single function you write will be recursive**.

Many problems in computer science lend themselves to a recursive formulation. These are naturally solved by recursive solutions.

We will see that lists, trees, and other important structures employ a simple recursive description.

Programs are simpler and more understandable when viewed in a mathematical lens.

Functional programming allows reasoning about programs and their subcomponents in the same way that you would reason about a mathematical expression.

Furthermore, mathematical analysis of code grants techniques to reason about things like time complexity, parallel time complexity, and program correctness. Functional programs are very amenable to proofs of correctness!

We're not just in the business of writing code, but *correct* code!

Before, we described programming as an explanatory, communicative process.

We also stated how *descriptivity* and *maintainability* are key goals for good programming.

Functional programming places a great emphasis on *types*, which serve the purpose of documenting the purpose of code, and restricting the range of behaviors that a program is allowed to exhibit.

In this way, types guide the structure of a program, by providing clean interfaces for how different parts should interact, and what it should be allowed to do.

3 - Types, Expressions, Values

In this class, we will be using a functional programming language called Standard ML (SML).

Mantra In Standard ML, **computation is evaluation**.

Evaluation of what, though? The most fundamental unit of an SML program is called an **expression**.

Def An **expression** is the building block of an SML program. These may or may not evaluate to a value.

Def A **value** is a **final answer**, that cannot be simplified further.

Examples of values include `2`, `"hi"`, and `true`.

Examples of expressions include `2`, `2 + 2`, and `4 * 5`

To evaluate an expression like `(2 + 3) * 4`, we apply simplifying rules. So we get:

$$\begin{aligned} \texttt{(2 + 3) * 4} &\Longrightarrow \texttt{5 * 4} \\ &\Longrightarrow \texttt{20} \end{aligned}$$

Def We use the $\Longrightarrow$ symbol to denote **stepping** (or **reducing**) of expressions, which means to simplify an expression by one step.

Def We use the $\Longrightarrow^*$ symbol to denote the application of the $\Longrightarrow$ relation an arbitrary number of times, usually until completion.

So the expression `5 * 4` *steps to* the expression `20`, and the expression `(2 + 3) * 4` $\Longrightarrow^*$ `20`.

We call the previous slide the **computation trace** of the expression `(2 + 3) * 4`.

The goal of a computation trace is to produce a value.

If we know that the expression `e` eventually reduces down to value `v`, we might say that `e` reduces to `v`, or write `e` $\hookrightarrow$ `v`. We then say that `e` is **valuable**.

So `(2 + 3) * 4` $\hookrightarrow$ `20`.

We said before that the goal of a computation trace is to produce a value, but not all expressions do!

What value does the expression `1 div 0` reduce to?

The answer: **there is no such value!** Division by zero is undefined, and in Standard ML, raises an exception.

Evaluating an expression has three possible behaviors:

- Reducing to a value
- Raising an exception
- Looping forever

In Standard ML, the string concatenation operator is `^`.

So we would say that `"hi" ^ "there"` $\Longrightarrow$ `"hithere"`.

But what does `"1" ^ 50` step to?

Some programming languages might try to make sense of this expression.

Standard ML will not.

Def A **type** is a specification of the behavior of a piece of code. It **predicts** what a program is allowed to do.

We write `e : t` to say that the expression `e` has type `t`, so we could write `1 + (2 * 3) : int`.

For instance, something with type `int` must produce a number, if it reduces to a value.

Similarly with something of type `string`.

What can we say about the runtime behavior of `"1" ^ 50`? It's not clear, so the expression `"1" ^ 50` **does not have a type**.

How does Standard ML know the type of an expression?

It follows **typing rules** to determine this. For instance:

Def The typing rule for + is: `e1 + e2 : int` if `e1 : int` and `e2 : int`

Take the expression `1 + (2 + 3)`.

Then, we know `1 + (2 + 3) : int` if `1 : int` and `2 + 3 : int`.

We know `1 : int`.

Then, we know `2 + 3 : int` if `2 : int` and `3 : int`.

We know `2 : int`.

We know `3 : int`.

So `1 + (2 + 3) : int`.

What about for `"1" ^ 50`?

Def The typing rule for `^` is: `e1 ^ e2 : string` if `e1 : string` and `e2 : string`

Take the expression `"1" ^ 50`.

Then, we know `"1" ^ 50 : string` if `"1" : string` and `50 : string`.
We know `"1" : string`.
However, it is not true that `50 : string`, because `50 : int`.

So `"1" ^ 50` does not have a type, and we say it is an **ill-typed expression**.

SML is a **statically typed** language, meaning that all typing rules are applied **before the program is ever run**.

Def We say that a piece of code or a program which obeys all the typing rules **type-checks**, or is **well-typed**.

Key **Ill-typed programs are not evaluated.**

4 - Declarations

We've so far discussed types and values, but we haven't introduced the machinery we need to actually work in a programming language! We need some way to declare variables and functions.

In SML, we can declare functions using the `fun` syntax:

```
fun double (n : int) : int = n + n
```

This comprises of a few parts:

- the `fun` keyword that signals the start of the declaration
- the name of the function (`double`)
- the arguments to the function, annotated with type (`n` and `int`)
- the return type of the function (`int`)
- the body of the function `n + n`

To use the function we just defined, we have to **apply** it. This is done via placing the function expression directly adjacent to the argument that it is meant to take in.

So for instance, instead of writing `double(2)` like we would in some programming languages, we would write `double 2`. This is known as **function application**.

So we would have that `double 2` $\Longrightarrow$ `4`.

Since `double` is a function which takes in an `int` and returns an `int`, we would refer to it as having the **function type** `int -> int`.

How do we know that `double : int -> int`, however? Is it just because we annotated it as taking in `int` and returning `int`?

That isn't true, however, because the following declaration fails to type-check, and thus will not be executed by Standard ML:

```
fun double (n : int) : string = n + n
```

In reality, SML is checking the type of `double` to make sure that it is consistent with the annotations that we state.

```
fun double (n : int) : int = n + n
```

To check the type of `double`, SML will take our word for what the input type of `n` is, here.

It will then try to produce a type for the body of the function, *given that* `n : int`. If that matches up with the return type as stated, then the function is well-typed.

In this case, we see that if `n : int`, then by our previous logic `n + n : int`, which matches the return type. When we change it to `string` however, that becomes different, so the declaration is rejected as ill-typed.

How do we know that `double 2` is well-typed?

Def The typing rule for function application is that `e1 e2 : t2` iff `e1 : t1 -> t2` and `e1 : t1`, for some types `t1`, `t2`.

In essence, this is saying applying a function only returns a type `t2` if the function has type `t1 -> t2`, and it is given an input of type `t1`.

In this case we know `double 2 : int` if `double : int -> int` and `2 : int`.
We know `double : int -> int`, because of our previous reasoning.
We also know that `2 : int`.

So `double 2 : int`, the return type of `double`.

Now we need to cover how to declare variables. The key word of interest here is `val`.

```
val favoriteCourseNumber : int = 150
```

It functions similarly to a function declaration, but there are now no arguments to type-annotate.

We will have more to say about variable declarations in the next lecture.

5 - Closing Remarks

Let's discuss the elephant in the room.

We live in unprecedented times, where classrooms and software engineering are being disrupted by the rise of large language models and agentic coding assistants.

It would be wrong of me as your instructor to not acknowledge this, and the fundamental question: **why are we here, learning functional programming?**

What is the point of us learning how to write programs which can be generated by an LLM?

How many of you want to be software engineers?

How many of you are worried about having difficulty finding an entry-level job due to AI? About being replaced by AI?

I cannot promise to you answers to all of these worries. What I can tell you is that there has never been a better time to really care about the material you have the opportunity to learn.

In a world where generating code via LLMs is cheap, the ability to discern good solutions and reason about code is more valuable than ever.

They[a] say that taste is the one thing that AI cannot replicate.

Key Generativity without constraint is chaos!

Without the ability to appraise the solutions that are presented to you, programming becomes a mess.

You need to be able to choose what to do, and what to not do, and you cannot do that without first understanding the relative merits of different code.

Is Taste the One Thing A.I. Can’t Replace?

Anxious tech workers in Silicon Valley are trying to cultivate a quality they say ChatGPT can’t provide.

[a] The New York Times, that is.

I promised you at the start of this lecture that I would change the way that you think.

The point of 15-150 is not functional programming. Functional programming is a tool, a paradigm, and an art. But most of all, it is a way of thinking.

Ideas from functional programming are not just pervasive among many disciplines of programming and in many programming languages, but they make you a stronger problem solver and better architect of code.

You are at Carnegie Mellon University, an institution that is special in teaching you a subject that most never get the chance to learn.

I intend to keep my promise.

Thank you!