COMP3141

Software System Design and Implementation

Introduction

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CSE, UNSW (and data61)
Term 2 2019

Who are we?

I am Liam O'Connor, a casual academic at UNSW. I do research work on formal methods and programming languages with various companies and the people at data61.

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Prof. Gabriele Keller, who now works at Utrecht University, is the former lecturer of this course. Her research interests revolve around programming languages for formal methods and high performance computing. Hopefully we can maintain the high standard she set.

Contacting Us

`http://www.cse.unsw.edu.au/~cs3141`

Forum

There is a Piazza forum available on the website. Questions about course content should typically be made there. You can ask us private questions to avoid spoiling solutions to other students.

I highly recommend disabling the Piazza Careers rubbish.

Administrative questions should be sent to `liamoc@cse.unsw.edu.au`.

What is this course?

Software must be high quality:
correct, safe and secure.

Software must developed
cheaply and quickly

Safety-uncritical Applications

;

Video games: Some bugs are acceptable, to save developer effort.

Safety-critical Applications

Imagine you...

- Are travelling on a plane
- Are travelling in a self-driving car
- Are working on a Mars probe
- Have invested in a new hedge fund
- Are running a cryptocurrency exchange
- Are getting treatment from a radiation therapy machine
- Intend to launch some nuclear missiles at your enemies

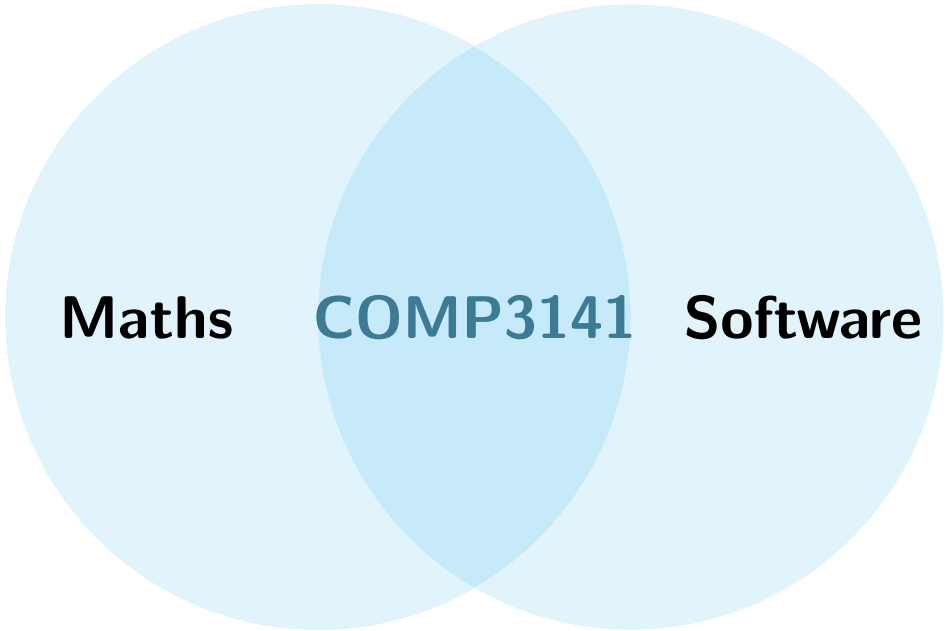
...running on software written by the person next to you.

Safety-critical Applications

Airline Blames Bad Software in San Francisco Crash

The New York Times

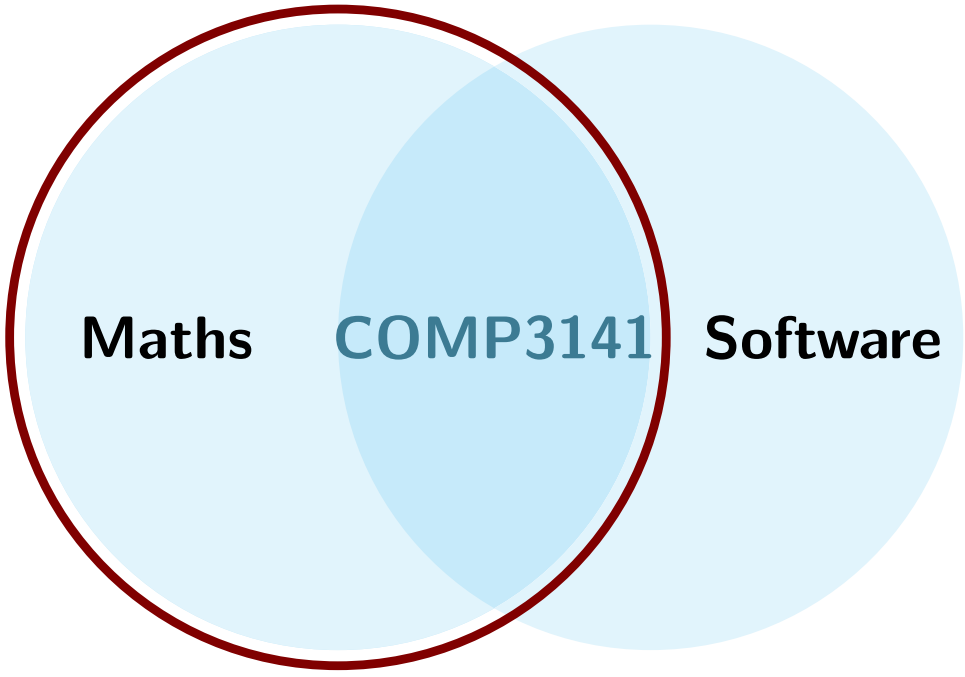
What is this course?



What is this course?

Maths?

- Logic
- Set Theory
- Proofs
- Induction
- Algebra (a bit)
- No calculus ☺

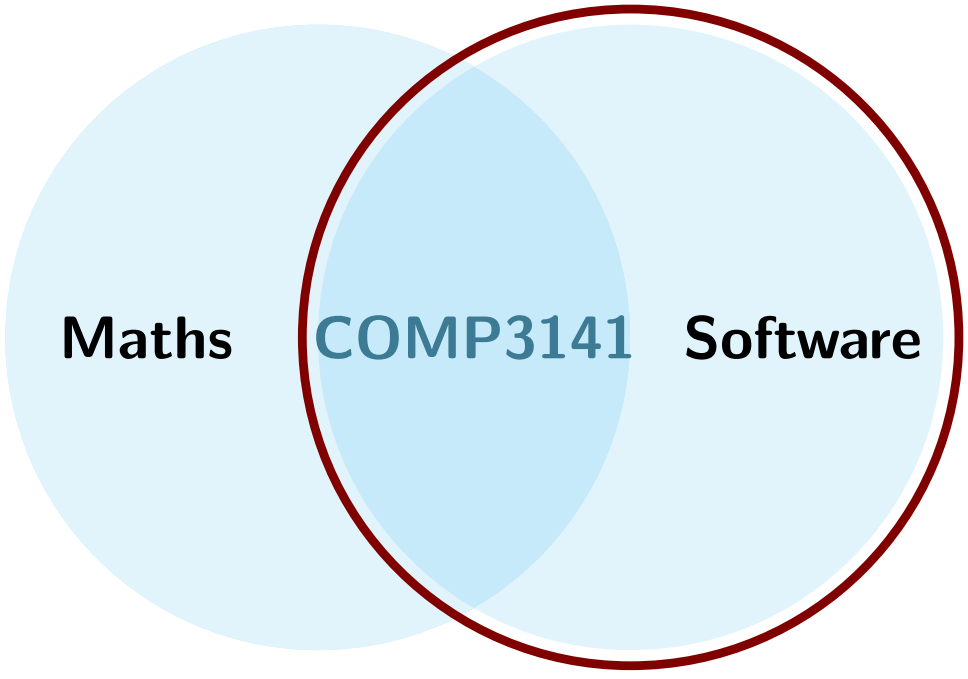


N.B: MATH1081 is neither necessary nor sufficient for COMP3141.

What is this course?

Software?

- Programming
- Reasoning
- Design
- Testing
- Types
- Haskell



N.B: Haskell knowledge is not a prerequisite for COMP3141.

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- **a Haskell course**

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- **a Haskell course**
- a formal verification course (for that, see COMP4161)
- an OOP software design course (see COMP2511, COMP1531)
- a programming languages course (see COMP3161).
- a WAM booster cakewalk (hopefully).
- a soul-destroying nightmare (hopefully).

Assessment

Warning

For many of you, this course will present a lot of new topics. Even if you are a seasoned programmer, you may have to learn as if from scratch.

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- Class Mark (out of 100)
  - **Two** programming assignments, each worth 20 marks.
  - Weekly online quizzes, worth 20 marks.
  - Weekly programming exercises, worth 40 marks.
- Final Exam Mark (out of 100)

$$result = \frac{2 \cdot class \cdot exam}{class + exam}$$

Lectures

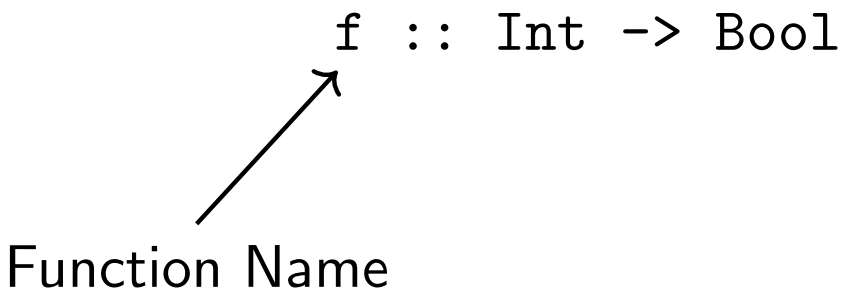
- There is one stream of lectures, and a (hurk!) web stream.
- I will generally run lectures introducing new material on Tuesday, and Christine will reinforce this material with questions and examples on Wednesday.
- Web stream students must watch recordings as they come out.
- Recordings are available through echo 360. I will try my best to make these usable.
- All board-work will be done digitally and made available to you.
- Online quizzes are due one week after the lectures they examine, but do them early!

Books

There are no set textbooks for this course, however there are various books that are useful for learning Haskell listed on the course website.
I can also provide more specialised text recommendations for specific topics.

Haskell

In this course we use Haskell, because it is the most widespread language with good support for mathematically structured programming.



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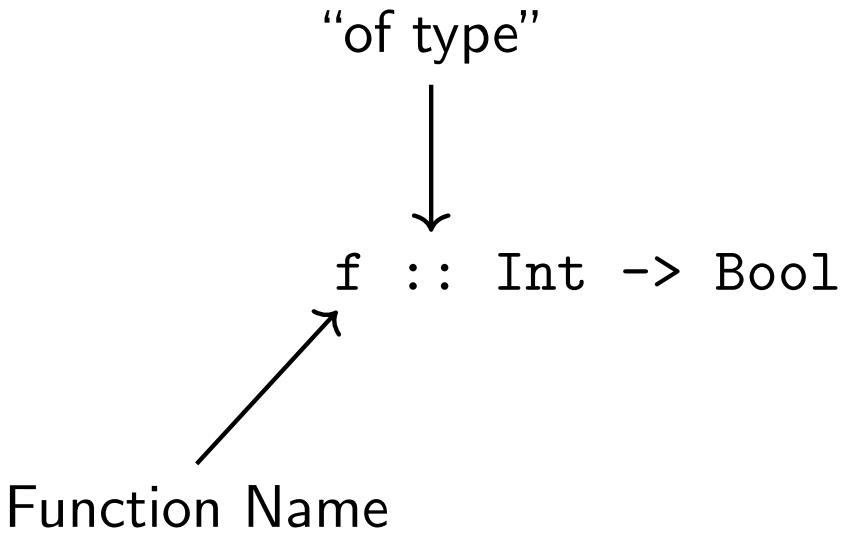

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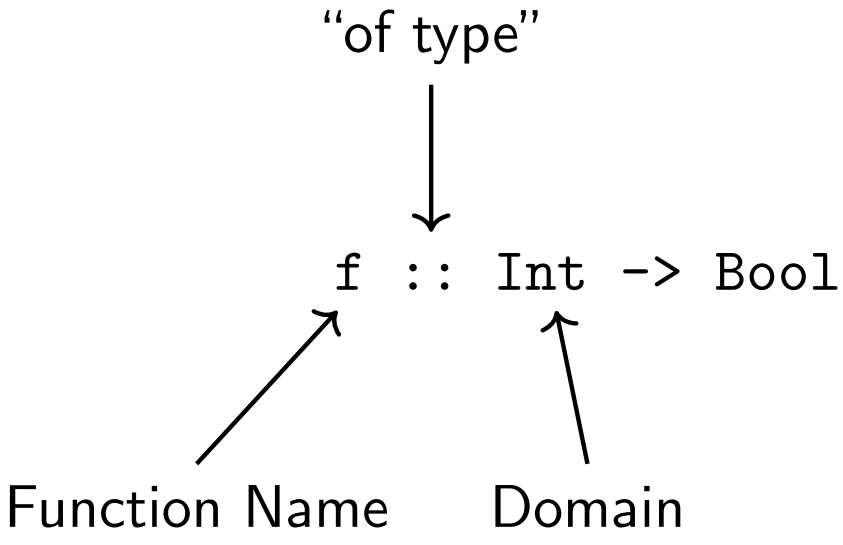

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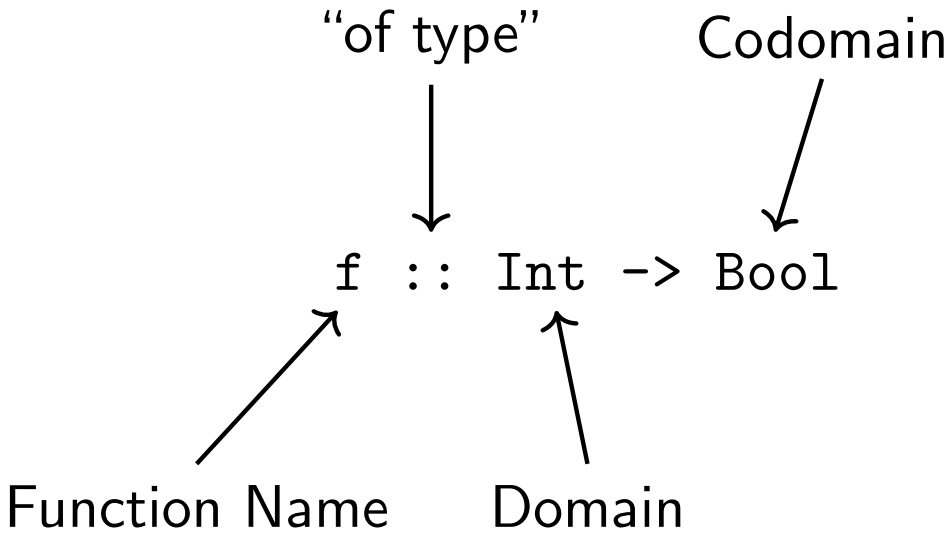

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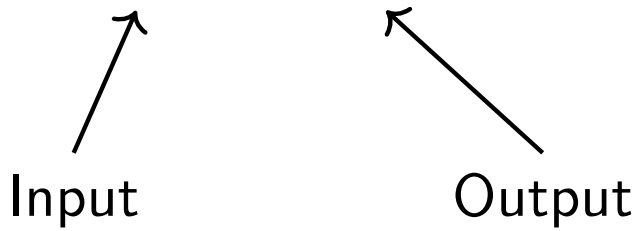
```
f :: Int -> Bool
f x = (x > 0)
```



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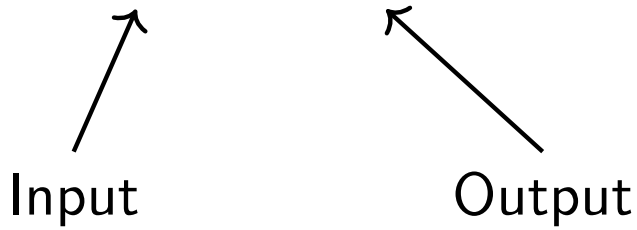

In mathematics, we would apply a function by writing $f(x)$. In Haskell we write `f x`.

Demo: GHCi, basic functions

Currying

- In mathematics, we treat $\log_{10}(x)$ and $\log_2(x)$ and $\ln(x)$ as separate functions.
- In Haskell, we have a single function `logBase` that, given a number n, produces a function for $\log_n(x)$.

```
log10 :: Double -> Double
log10 = logBase 10

log2 :: Double -> Double
log2 = logBase 2

ln :: Double -> Double
ln = logBase 2.71828
```

What's the type of `logBase`?

Currying and Partial Application

```
logBase :: Double -> (Double -> Double)
```

(parentheses optional above)

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Function application associates to the **left** in Haskell, so:

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logBase 2 64  ≡  (logBase 2) 64
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Function application associates to the **left** in Haskell, so:

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logBase 2 64   ≡   (logBase 2) 64
```

Functions of more than one argument are usually written this way in Haskell, but it is possible to use tuples instead...

Tuples

Tuples are another way to take multiple inputs or produce multiple outputs:

```
toCartesian :: (Double, Double) -> (Double, Double)
toCartesian (r, theta) = (x, y)
    where x = r * cos theta
          y = r * sin theta
```

N.B: The order of bindings doesn't matter. Haskell functions have no side effects, they just return a result.

Higher Order Functions

In addition to returning functions, functions can take other functions as arguments:

```
twice :: (a -> a) -> (a -> a)
twice f a = f (f a)

double :: Int -> Int
double x = x * 2

quadruple :: Int -> Int
quadruple = twice double
```

Lists

Haskell makes extensive use of lists, constructed using square brackets. Each list element must be of the same type.

```
[True, False, True]    ::   [Bool]
[3, 2, 5+1]            ::   [Int]
[sin, cos]             ::   [Double -> Double]
[ (3,'a'),(4,'b') ]    ::   [(Int, Char)]
```

Map

A useful function is `map`, which, given a function, applies it to each element of a list:

```
map not [True, False, True] = [False, True, False]
map negate [3, -2, 4]       = [-3, 2, -4]
map (\x -> x + 1) [1, 2, 3] = [2, 3, 4]
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The last example here uses a *lambda expression* to define a one-use function without giving it a name.

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```
map :: (a -> b) -> [a] -> [b]
```

Strings

The type `String` in Haskell is just a list of characters:

```
type String = [Char]
```

This is a *type synonym*, like a `typedef` in C.

Thus:

```
"hi!" == ['h', 'i', '!']
```

Word Frequencies

Let's solve a problem to get some practice:

Example (First Demo Task)

Given a number n and a string s, generate a report (in `String` form) that lists the n most common words in the string s.

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Given a number n and a string s, generate a report (in `String` form) that lists the n most common words in the string s.

We must:

1. Break the input string into words.
2. Convert the words to lowercase.
3. Sort the words.
4. Count adjacent runs of the same word.
5. Sort by size of the run.
6. Take the first n runs in the sorted list.
7. Generate a report.

Function Composition

We used *function composition* to combine our functions together. The mathematical $(f \circ g)(x)$ is written `(f . g) x` in Haskell.

In Haskell, operators like function composition are themselves functions. You can define your own!

```
-- Vector addition
(.+) :: (Int, Int) -> (Int, Int) -> (Int, Int)
(x1, y1) .+ (x2, y2) = (x1 + x2, y1 + y2)
```

```
(2,3) .+ (1,1) == (3,4)
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You could even have defined function composition yourself if it didn't already exist:

```
(.) :: (b -> c) -> (a -> b) -> (a -> c)
(f . g) x = f (g x)
```

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How were all of those list functions we just used implemented?

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Lists are singly-linked lists in Haskell. The empty list is written as `[]` and a list node is written as `x : xs`. The value `x` is called the head and the rest of the list `xs` is called the tail. Thus:

```
"hi!" == ['h', 'i', '!'] == 'h':('i':('!':[]))
                         == 'h' : 'i' : '!' : []
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                         == 'h' : 'i' : '!' : []
```

When we define recursive functions on lists, we use the last form for pattern matching:

```
map :: (a -> b) -> [a] -> [b]
map f []     = []
map f (x:xs) = f x : map f xs
```

Equational Evaluation

```
map f []     = []
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We can evaluate programs *equationally*:

```
map toUpper "hi!"
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                   ≡  'H' : 'I' : '!'  :  map toUpper ""
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                   ≡  'H' : 'I' : '!'  :  map toUpper ""
                   ≡  'H' : 'I' : '!'  :  map toUpper []
                   ≡  'H' : 'I' : '!'  :  []
                   ≡  "HI!"
```

Higher Order Functions

The rest of this lecture will be spent introducing various list functions that are built into Haskell's standard library by way of live coding.

Functions to cover:

1. `map`
2. `filter`
3. `concat`
4. `sum`
5. `foldr`
6. `foldl`

In the process, we will introduce **let** and **case** syntax, **guards** and **if**, and the $ operator.

Homework

1. Get Haskell working on your development environment. Instructions are on the course website.
2. Using Haskell documentation and GHCi, answer the questions in this week's quiz (assessed!).