# COMP3141

Software System Design and Implementation



## Functional Programming Practice

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# Recap: What is this course?

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

Software must developed **cheaply and quickly**

# Recall: Safety-critical Applications



For safety-critical applications, failure is not an option:

- planes, self-driving cars
- rockets, Mars probe
- drones, nuclear missiles
- banks, hedge funds, cryptocurrency exchanges
- radiation therapy machines, artificial cardiac pacemakers

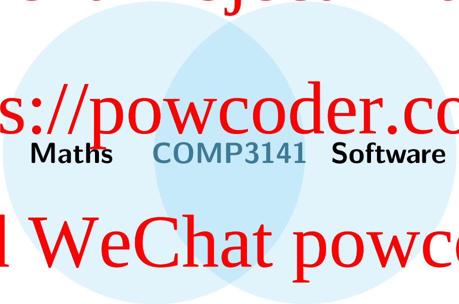
# Safety-critical Applications



A bug in the code controlling the Therac-25 radiation therapy machine was directly responsible for at least five patient deaths in the 1980s when it administered excessive quantities of beta radiation.

# COMP3141: Functional Programming





# Functional Programming: How does it Help?



1. Close to Maths: more abstract, less error-prone
2. Types: act as doc., the compiler eliminates many errors
3. Property-Based Testing: QuickCheck (in Week 3)
4. Verification: equational reasoning eases proofs (in Week 4)

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# Functional Programming: History in Academia

**1930s** Alonzo Church developed lambda calculus (equiv. to Turing Machines)



**1950s** John McCarthy developed Lisp (LISt Processor, first FP language)

**1960s** Peter Landin developed ISWIM (If you See What I Mean, first pure FP language)

**1970s** John Backus developed FP (Functional Programming, higher-order functions, reasoning)



**1970s** Robin Milner and others developed ML (Meta-Language, first modern FP language, polymorphic types, type inference)



**1980s** David Turner developed Miranda (lazy, predecessor of Haskell)

**1987-** An international PL committee developed Haskell (named after the logician Curry Haskell)

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... received Turing Awards (similar to Nobel prize in CS).

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Functional programming is now taught at most CS departments.

# Functional Programming: Influence In Industry



- Facebook's motto was:
  - "Move fast and break things."
  - as they expanded, they understood the importance of bug-free software
  - now Facebook uses functional programming!



- JaneStreet, Facebook, Google, Microsoft, Intel, Apple
  (... and the list goes on)
- Facebook building React and Reason, Apple pivoting to Swift, Google developing MapReduce.

# Closer to Maths: Quicksort Example

Let's solve a problem to get some practice:



**Example (Quicksort, recall from Algorithms)**

Quicksort is a divide and conquer algorithm.

1. Picks a pivot from the array or list
2. Divides the array or list into two smaller sub-components: the smaller elements and the larger elements.
3. Recursively sorts the sub-components.

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- What is the worst case complexity of Quicksort?

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- What is the average complexity of Quicksort?
- What is the worst case complexity of Quicksort?
- Imperative programs describe **how** the program works.
- Functional programs describe **what** the program does.

## Quicksort Example (Imperative)

```
algorithm quicksort(A, lo, hi) is
    if lo < hi then
        p := partition(A, lo, hi)
        quicksort(A, lo, p - 1)
        quicksort(A, p + 1, hi)

algorithm partition(A, lo, hi) is
    pivot := A[hi]
    i := lo
    for j := lo to hi - 1 do
        if A[j] < pivot then
            swap A[i] with A[j]
            i := i + 1
    swap A[i] with A[hi]
    return i
```

## Quick Sort Example (Functional)



```haskell
qsort :: Ord a => [a] -> [a]
qsort [] = []
qsort (x:xs) = qsort smaller ++ [x] ++ qsort larger
               where
                smaller = filter (\ a-> a <= x) xs
                larger  = filter (\ b-> b > x) xs
```

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Is that it? Does this work?

## Practice Types

In the previous lecture, you learned about the importance of types in functional programming. Let's practice figuring out the types of terms.

1. `True`

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1. `True :: Bool`
2. `'a' :: Char`
3. `['a', 'b', 'c']`

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4. `"abc"`

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4. `"abc" :: [Char]`
5. `["abc"] :: [[Char]]`
6. `[('f',True), ('e', False)]`

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6. `[('f',True), ('e', False)] :: [(Char, Bool)]`

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4. `"abc" :: [Char]`
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6. `[('f',True), ('e', False)] :: [(Char, Bool)]`

- In Haskell and GHCi using `:t`.
- Using Haskell documentation and GHCi, answer the questions in this week's quiz (assessed!).

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# Recall: Higher Order List Functions

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



**Functions covered:**

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



In the process, you saw **guards** and **if**, and the `.` operator.

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6. `foldl`



In the process, you saw **guards** and **if**, and the `.` operator.

Let's do that again in Haskell.

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# Numbers into Words



Let's solve a problem to get some practice:

**Example (Demo Task)**

Given a number $n$, such that $0 \leq n < 1000000$, generate words (in `String` form) that describes the number $n$.

# Numbers into Words



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**Example (Demo Task)**

Given a number $n$, such that $0 \leq n < 1000000$, generate words (in `String` form) that describes the number $n$.



We must:

1. Convert single-digit numbers into words ($0 \leq n < 10$).
2. Convert double-digit numbers into words ($0 \leq n < 100$).
3. Convert triple-digit numbers into words ($0 \leq n < 1000$).
4. Convert hexa-digit numbers into words ($0 \leq n < 1000000$).

# Single Digit Numbers into Words

$$0 \leq n < 10$$



```
units :: [String]
units =
    ["zero", "one", "two", "three", "four", "five",
     "six", "seven", "eight", "nine", "ten"]
```

# Single Digit Numbers into Words

$$0 \leq n < 10$$



```
units :: [String]
units =
    ["zero", "one", "two", "three", "four", "five",
     "six", "seven", "eight", "nine", "ten"]

convert1 :: Int -> String
```

# Single Digit Numbers into Words

$$0 \leq n < 10$$



```haskell
units :: [String]
units =
    ["zero", "one", "two", "three", "four", "five",
     "six", "seven", "eight", "nine", "ten"]

convert1 :: Int -> String
convert1 n = units !! n
```

# Double Digit Numbers into Words

$$0 \leq n < 100$$



```haskell
teens :: [String]
teens =
    ["ten", "eleven", "twelve", "thirteen", "fourteen",
     "fifteen", "sixteen", "seventeen", "eighteen",
     "nineteen"]
```





```haskell
tens :: [String]
tens =
    ["twenty", "thirty", "fourty", "fifty", "sixty",
     "seventy", "eighty", "ninety"]
```

# Double Digit Numbers into Words Continued $(0 \leq n < 100)$



```
digits2 :: Int -> (Int, Int)
digits2 n = (div n 10, mod n 10)
```

# Double Digit Numbers into Words Continued $(0 \leq n < 100)$



```
digits2 :: Int -> (Int, Int)
digits2 n = (div n 10, mod n 10)
combine2 :: (Int, Int) -> String
```

# Double Digit Numbers into Words Continued $(0 \leq n < 100)$



```
digits2 :: Int -> (Int, Int)
digits2 n = (div n 10, mod n 10)
combine2 :: (Int, Int) -> String
combine2 (t, u)
    | t == 0            = convert1 u
```

# Double Digit Numbers into Words Continued $(0 \leq n < 100)$



```haskell
digits2 :: Int -> (Int, Int)
digits2 n = (div n 10, mod n 10)
combine2 :: (Int, Int) -> String
combine2 (t, u)
    | t == 0            = convert1 u
    | t == 1            = teens !! u
```

# Double Digit Numbers into Words Continued $(0 \leq n < 100)$



```haskell
digits2 :: Int -> (Int, Int)
digits2 n = (div n 10, mod n 10)
combine2 :: (Int, Int) -> String
combine2 (t, u)
    | t == 0                 = convert1 u
    | t == 1                 = teens !! u
    | t > 1 && u == 0        = tens !! (t-2)
```

# Double Digit Numbers into Words Continued $(0 \leq n < 100)$



```haskell
digits2 :: Int -> (Int, Int)
digits2 n = (div n 10, mod n 10)
combine2 :: (Int, Int) -> String
combine2 (t, u)
    | t == 0              = convert1 u
    | t == 1              = teens !! u
    | t > 1 && u == 0     = tens !! (t-2)
    | t > 1 && u /= 0     = tens !! (t-2)
                            ++ "-" ++ convert1 u
```

# Double Digit Numbers into Words Continued $(0 \leq n < 100)$



```
digits2 :: Int -> (Int, Int)
digits2 n = (div n 10, mod n 10)

combine2 :: (Int, Int) -> String
combine2 (t, u)
    | t == 0              = convert1 u
    | t == 1              = teens !! u
    | t > 1 && u == 0     = tens !! (t-2)
    | t > 1 && u /= 0     = tens !! (t-2)
                            ++ "-" ++ convert1 u

convert2 :: Int -> String
```

# Double Digit Numbers into Words Continued

$(0 \leq n < 100)$



```haskell
digits2 :: Int -> (Int, Int)
digits2 n = (div n 10, mod n 10)
combine2 :: (Int, Int) -> String
combine2 (t, u)
    | t == 0            = convert1 u
    | t == 1            = teens !! u
    | t > 1 && u == 0   = tens !! (t-2)
    | t > 1 && u /= 0   = tens !! (t-2)
                          ++ "-" ++ convert1 u
convert2 :: Int -> String
convert2 = combine2 . digits2
```

# Infix Notation



Instead of

```
digits2 n = (div n 10, mod n 10)
```



for **infix** notation, write:

```
digits2 n = (n `div` 10, n `mod` 10)
```

# Infix Notation



Instead of

```haskell
digits2 n = (div n 10, mod n 10)
```



for **infix** notation, write:

```haskell
digits2 n = (n `div` 10, n `mod` 10)
```



Note: this is not the same as single quote used for `Char` (`'a'`).

# Simpler Guards but Order Matters



You could also simplify the guards as follows:

```
combine2 :: (Int, Int) -> String
combine2 (t,u)
   | t == 0      = convert1 u
   | t == 1      = teens !! u
   | u == 0      = tens !! (t-2)
   | otherwise   = tens !! (t-2) ++ "-" ++ convert1 u
```



but now the order in which we write the equations is crucial. `otherwise` is a synonym for `True`.

## Where instead of Function Composition



Instead of implementing `convert2` as `digit2.combine2`, we can implement it directly using the `where` keyword:



```
convert2 :: Int -> String
convert2 n
  | t == 0      = convert1 u
  | t == 1      = teens !! u
  | u == 0      = tens !! (t-2)
  | otherwise   = tens !! (t-2) ++ "-" ++ convert1 u
  where (t, u) = (n `div` 10, n `mod` 10)
```

# Triple Digit Numbers into Words

$(0 \leq n < 1000)$



```
convert3 :: Int -> String
```

# Triple Digit Numbers into Words

$(0 \leq n < 1000)$



```
convert3 :: Int -> String
convert3 n
    | h == 0     = convert2 n
```

# Triple Digit Numbers into Words

$(0 \leq n < 1000)$



```
convert3 :: Int -> String
convert3 n
    | h == 0      = convert2 n
    | t == 0      = convert1 h ++ "hundred"
```

## Triple Digit Numbers into Words

$(0 \leq n < 1000)$



```haskell
convert3 :: Int -> String
convert3 n
    | h == 0        = convert2 n
    | t == 0        = convert1 h ++ "hundred"
    | otherwise     = convert1 h ++ " hundred and "
                        ++ convert2 t
  where (h, t) = (n `div` 100, n `mod` 100)
```

## Hexa Digit Numbers into Words ($0 \leq n < 1000000$)



```
convert6 :: Int -> String
```

# Hexa Digit Numbers into Words

$(0 \leq n < 1000000)$



```
convert6 :: Int -> String
convert6 n
    |  m == 0      = convert3 n
```

# Hexa Digit Numbers into Words

$(0 \leq n < 1000000)$



```
convert6 :: Int -> String
convert6 n
    | m == 0        = convert3 n
    | h == 0        = convert3 m ++ "thousand"
```

# Hexa Digit Numbers into Words

$$(0 \leq n < 1000000)$$



```haskell
convert6 :: Int -> String

convert6 n
    |  m == 0        = convert3 n
    |  h == 0        = convert3 m ++ "thousand"
    |  otherwise     = convert3 m ++ link h ++ convert3 h
   where (m, h) = (n `div` 1000, n `mod` 1000)

link :: Int -> String
link h = if (h<100) then " and " else " "

convert :: Int -> String
convert = convert6
```

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# 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!).