# C/CPS 506



## Comparative Programming Languages



Prof. Alex Ufkes



**Topic 6:** Type systems, pure functional with Haskell

Ryerson University

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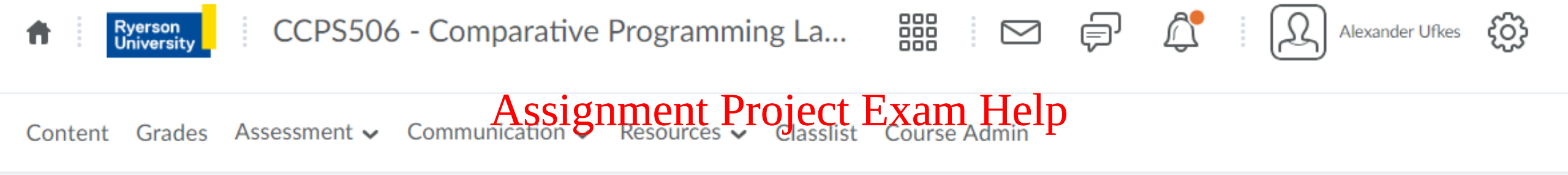
# Course Administration






**Elixir assignment due March 19**

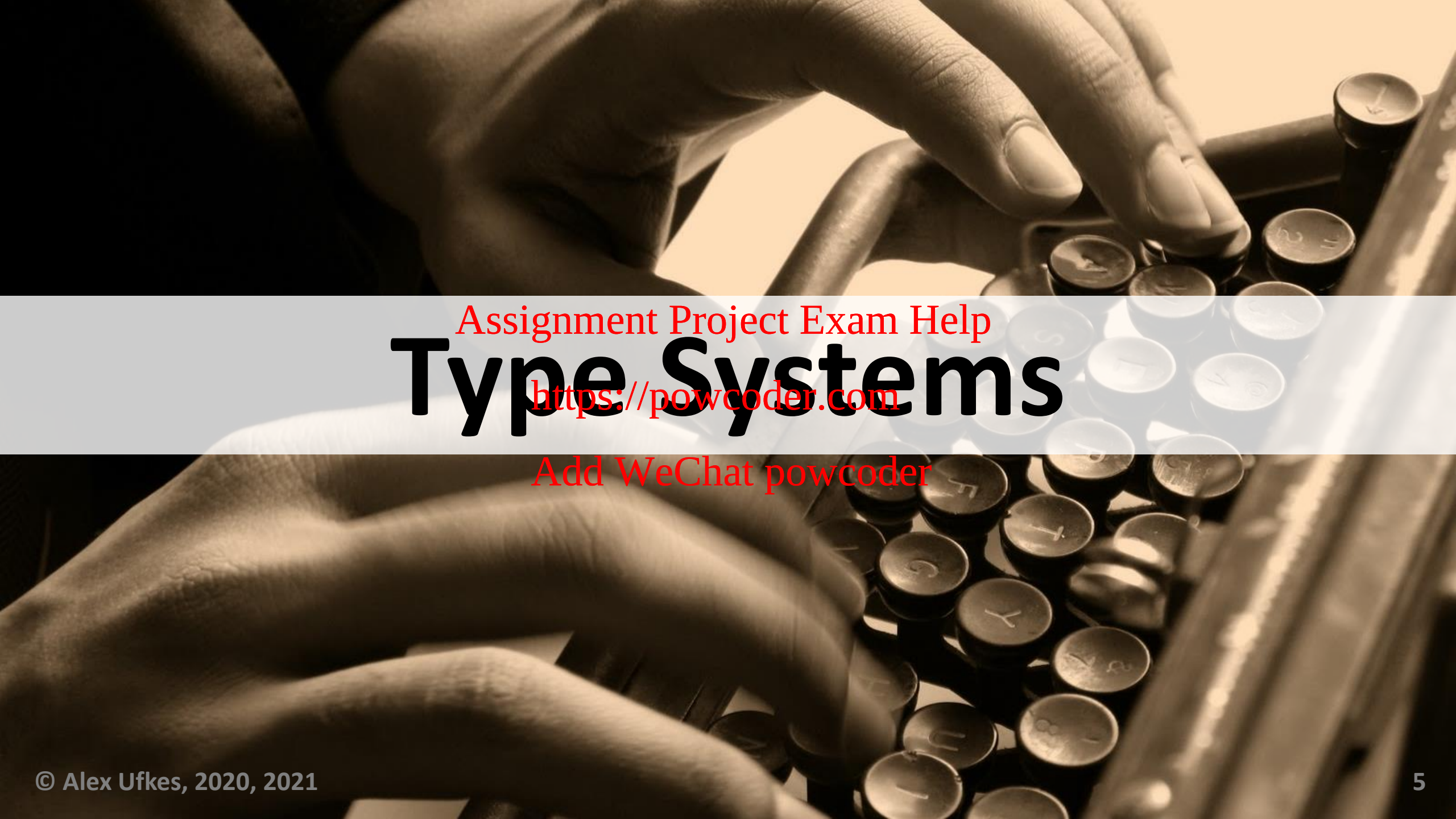
# Today

**Type systems:**

- Static VS dynamic
- Strong VS weak

**Intro to Haskell**

- Pure functional
- Typing in Haskell





# Type Systems

# Type System

- A set of rules that assigns a property called ***type*** to constructs of a program.
- These constructs include variables, functions, expressions, etc.



**The whole point is to reduce bugs.**



- For example, if a pattern of 32 bits has been encoded using 2s complement, we don't want to read it using IEEE 754
- And we *can* do this in many languages!

```c
#include <stdio.h>
#include <windows.h>

int main(void)
{
    unsigned long long a = 4607182418800017408;

    printf("as integer:  %llu\n", a);
    printf("as double:   %lf\n", a);

    system("pause");
}
```

Declare large 64-bit integer

Print as int, print as double



D:\GoogleDrive\Teaching - Humber\ATMN 253\Visual S

```
as integer:  4607182418800017408
as double:   1.000000
Press any key to continue . . .
```

- The 2s comp bit pattern was read as an IEEE 754 double.
- (The integer constant was deliberately picked to produce a bit pattern that would yield 1.000000 as double)

# Type Checking

Clearly, type checking isn't performed in the context of a **`printf`** statement in C++



- Think of type checking as trying to fit puzzle pieces together.
- Does the output type of a function match the variable we're trying to store it in?
- Do the input arguments to a function match the types indicated in the parameter list?
- If no, will we allow implicit conversion?

# Static VS Dynamic

When are types checked?

Statically typed languages perform type checking at *compile time*

- Checked while converting source code to machine (or byte) code

Dynamically typed languages perform type checking at *run-time*

- Checked on the fly while instructions are being executed.



**Statically Typed languages:** C/C++, Java, Haskell, Rust

**Dynamically Typed languages:** Python, Smalltalk, Elixir

# Static Type Checking

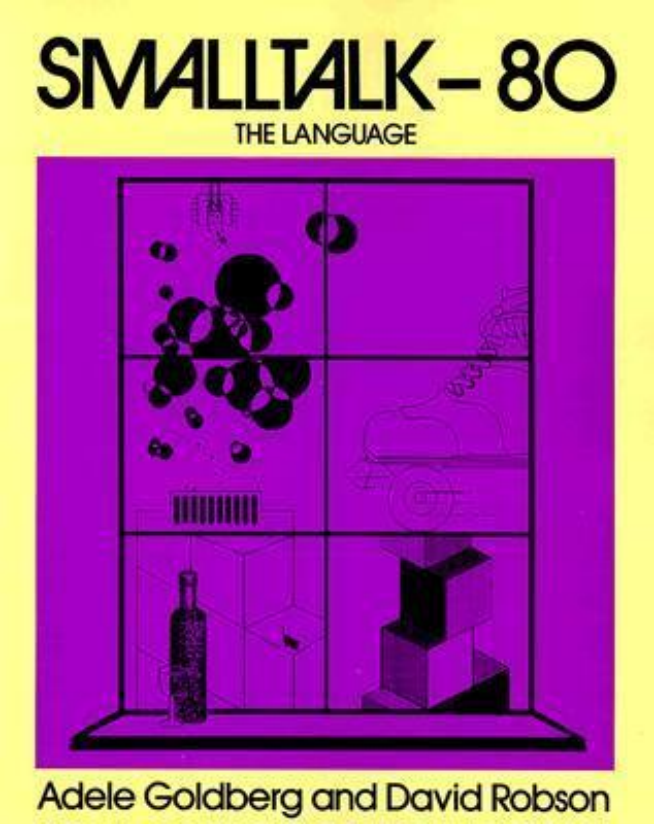
```
public class MethodTester
{
    public static void main(String[] args)
    {
        String s = "Hello";

        System.out.println(Math.sqrt(s));
    }
}
```



```
incompatible types: java.lang.String cannot be
converted to double
```

- In dynamically typed languages, every operation knows the types for which it is valid.
- Providing invalid arguments or operands will yield a run-time error which may or may not be recoverable
- Such things can be anticipated and mitigated in various ways, such as verifying type explicitly

# Dynamic Type Checking




```
factorial: n
  | fac |
  fac := 1.

  n isInteger
    ifTrue: [1 to: n do:
      [:a | fac := fac*a].
      ^fac
    ]
    ifFalse: [
      ^'Bad input'
    ].
```

- In Java, the parameter would be defined as **`int`**
- Compile error if arg isn't **`int`**, or can't be implicitly cast as an **`int`**.

- Of course, polymorphism in Java complicates this.
- Still statically typed.

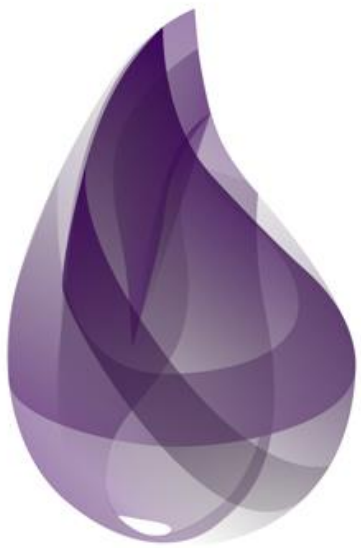
# Dynamic Type Checking…?

```
#(1 2 3 4) + 18.2
```



- Does Smalltalk have type errors in the strict sense?
- Different objects understand different messages.
- A “type error” occurs when an object doesn’t have a method to handle a particular message.
- “Type” errors in Smalltalk are as a result of not finding a method (DNU, Did Not Understand).
- Above, the error occurs because the Array class doesn’t have an instance ***method*** for symbolic operator **#+**
- Smalltalk enthusiasts debate this.

# Dynamic Type Checking



```
defmodule UserMath do
  def fib(n) when not is_integer(n) or n < 0 do
    :error
  end
  def fib(0), do: 0
  def fib(1), do: 1
  def fib(n), do: fib(n-2) + fib(n-1)
  def fac(n) when not is_integer(n) or n < 0 do
    :error
  end
  def fac(0), do: 1
  def fac(n), do: n*fac(n-1)
end
```

# Static VS Dynamic

**Advantages? Disadvantages?**



**Static:**

- Reliably find errors at compile time.
- Code will execute faster if types are assumed to be correct at run time.
- Type-specific optimization can be performed at compile time.
- I.e., integer arithmetic is faster than floating point





**Dynamic:**

- Compilers run faster
- Interpreters can dynamically load new code
  - Smalltalk, MATLAB, iex
- Easier code reuse

# Static VS Dynamic

**Advantages? Disadvantages?**



- There is much disagreement among programmers about just how much of a problem type errors are in the grand scheme of things.



- Does the added cost of developing in a statically typed language make sense if type-related bugs are but a tiny fraction?



- Of the type-related bugs that occur, what proportion of those would have been solved by a type checker anyway?
- They aren't perfect after all.

# Strong VS Weak Typing

# Strong VS Weak (or *Loose*)

Refers to how strict statically typed languages are at compile time

There is actually no universally accepted definition of what constitutes strong or weak typing





Of strongly typed languages:



**1974:** "Whenever an object is passed from a calling function to a called function, its type must be ***compatible*** with the type declared in the called function."

***Compatible*** is open to interpretation. Is float compatible with double? Integer with short integer?

# Strong VS Weak (or *Loose*)

Refers to how strict statically typed languages are at compile time

**1974:** "Whenever an object is passed from a calling function to a called function, its type must be compatible with the type declared in the called function."



**1977:** "In a strongly typed language each data area will have a distinct type and each process will state its ***communication requirements*** in terms of these types."



Parameter lists, return types, etc.

# Strong VS Weak (or *Loose*)

To what degree does a statically typed language allow implicit type conversion?

Quincy 2005 - [Text1]

File Edit View Project Debug Tools Window Help

```
#include <stdio.h>

int main(void)
{
    int y = 3.4;

    printf("%d\n", y);
}
```



Build

"D:\Programs\quincy\Min
"D:\Programs\quincy\Min
Successful build

"D:\Programs\quincy\Min
"D:\Programs\quincy\Min
Successful build

quincy

```
3

Press Enter to return to Quincy...
```

- C is weakly typed.
- Happy to perform all manner of implicit conversion without warning or error.

# Strong VS Weak (or *Loose*)

In C, pointer arithmetic can be used to ***completely bypass*** the type system:

Quincy 2005 - [Text1]

File Edit View Project Debug Tools Window Help

```c
#include <stdio.h>

int main(void)
{
    int x = 3357986;

    short a = *((short*)&x) + 1;

    printf("%d\n", a);
}
```

Press F1 for help  Ln 13, Col 1

- We're using pointer arithmetic to read the first 2 bytes of an **`int`** as a **`short`**.
- This can be done with any two types.
- We can read the rightmost 4 bytes of a **`double`** as an **`int`**, etc.
- We can treat memory any way we want

quincy

```
15651

Press Enter to return to Quincy...
```

# Strong VS Weak (or *Loose*)

C++ will give warnings where C did not, but still compiles and runs in this case:

```
#include <stdio.h>
#include <windows.h>

int main(void)
{
    int x = 57.99;

    print

    syste
}
```

```
C:\Users\aufke\Desktop\test\Debug\test.exe
57
Press any key to continue . . .
```

```
guration: Debug Win32 ------
 warning C4244: 'initializing' : conversion from 'double' to 'int', possible loss of data
est\Debug\test.exe
-to-date, 0 skipped ==========
```

# Strong VS Weak (or *Loose*)

Java will throw compile errors when a ***loss of precision*** occurs:

```
public class MethodTester
{
    public static void main(String[] args)
    {
        int a = 7.7;
        float b = 7.7;
        float c = 7.7f;
        double d = 7.7;
    }
}
```



- No implicit truncation from floating point to integer
- Floating point constants are double precision
- Need to indicate single precision explicitly

*Java will throw compile errors when a loss of precision occurs:*

**<u>Careful!</u>** Loss of precision does not ***only*** occur when going from floating point type to integer type!



`int` is 32 bits two's complement.



`float` is a 23-bit mantissa and an 8 bit exponent.



**32-bit:**

0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

sign bit

Exponent (8 bits)

Mantissa (23 bits)

# Imprecision of Floating Point

- Integers are represented *precisely.* The integer 42 is **exactly** 42.
- The single-precision (32 bits) floating point value 0.1 is ***actually*** 0.100000001490116119384765625
- *Double*-precision (64 bit) floating point values are more accurate, but still not perfect.



**But why?**

- Floating point values exist on an infinite continuum.
- Between any two floating point values are an ***infinite*** number of additional floating point values.
- Integers are discrete. Between any two integers are a ***finite*** number of integers.

# Imprecision of Floating Point

- A double-precision float is represented using 64 bits.
- A ***finite*** number of bits cannot represent an ***infinite*** number of floating point values.



**0100101110000010100010100001010100011010101011000110001110000011**



- There are **2^64** ways to arrange 64 bits. A large number to be sure, but certainly not infinite.

# Infinite Integers?

**But there are an infinite number of integers!**

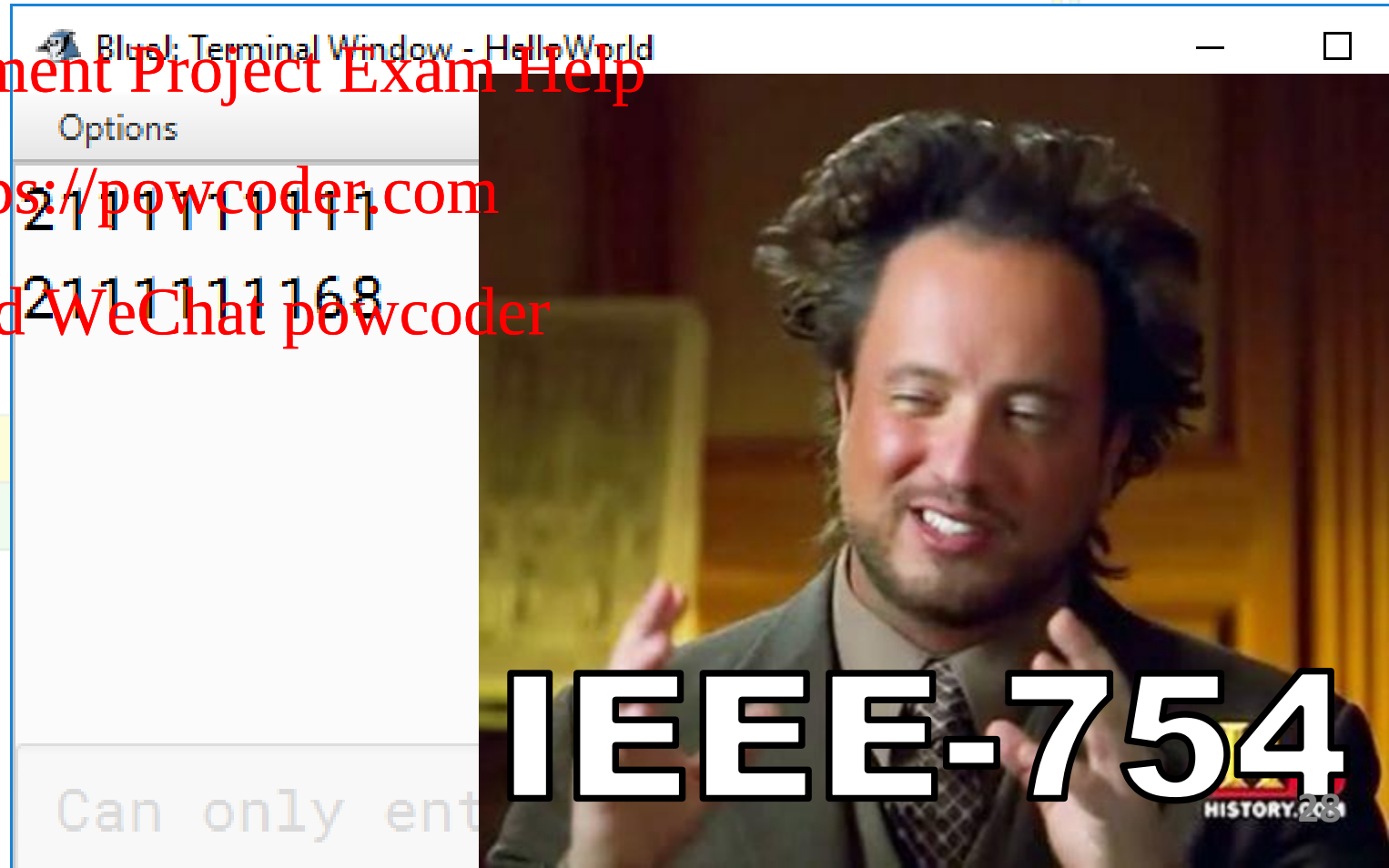
- 100% correct. We can't represent every possible integer either.
- Rather, there is a range. A standard 32-bit integer has a range of −2,147,483,648 to 2,147,483,647.
- Every integer within this range is represented precisely.
- Anything outside this range can't be represented using 32 bits
- If we try, we overflow.

```java
public class MethodTester
{
    public static void main(String[] args)
    {
        int a = 2111111111;
        System.out.println(a);

        float b = a;
        a = (int) b;

        System.out.println(a);
    }
}
```

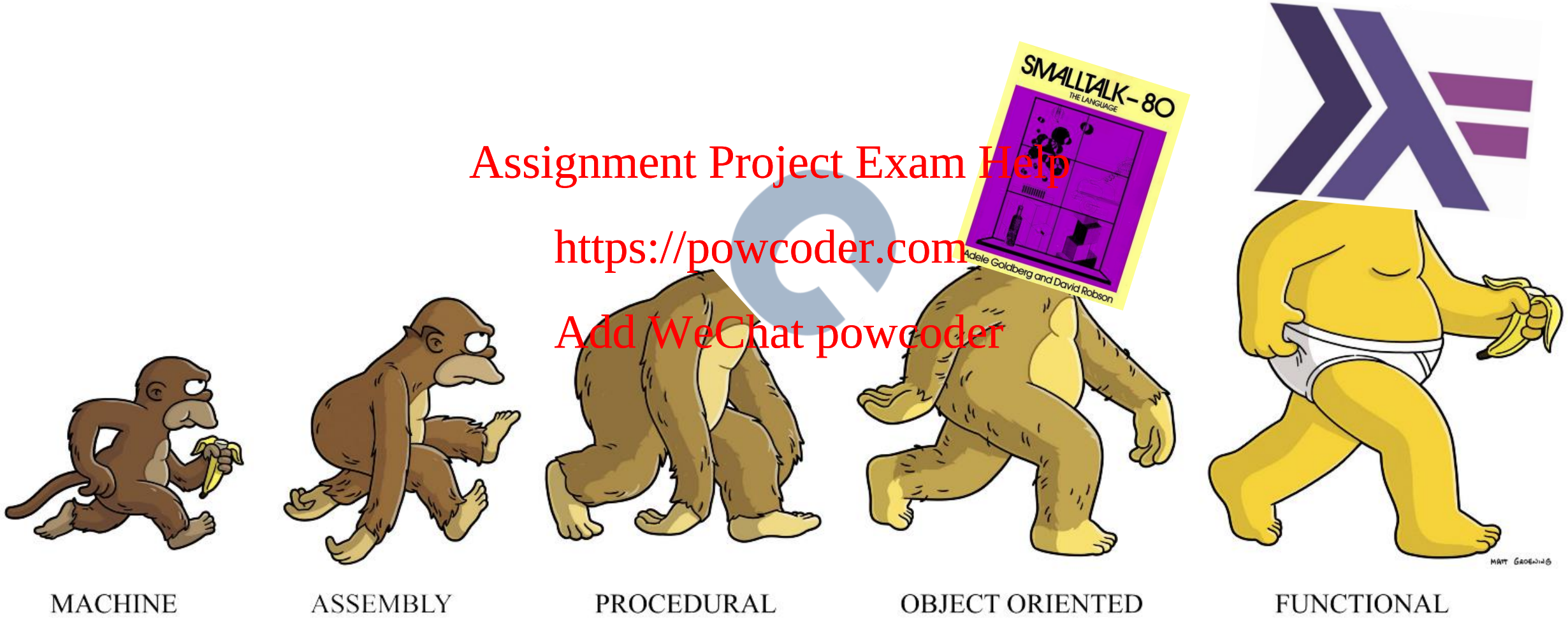


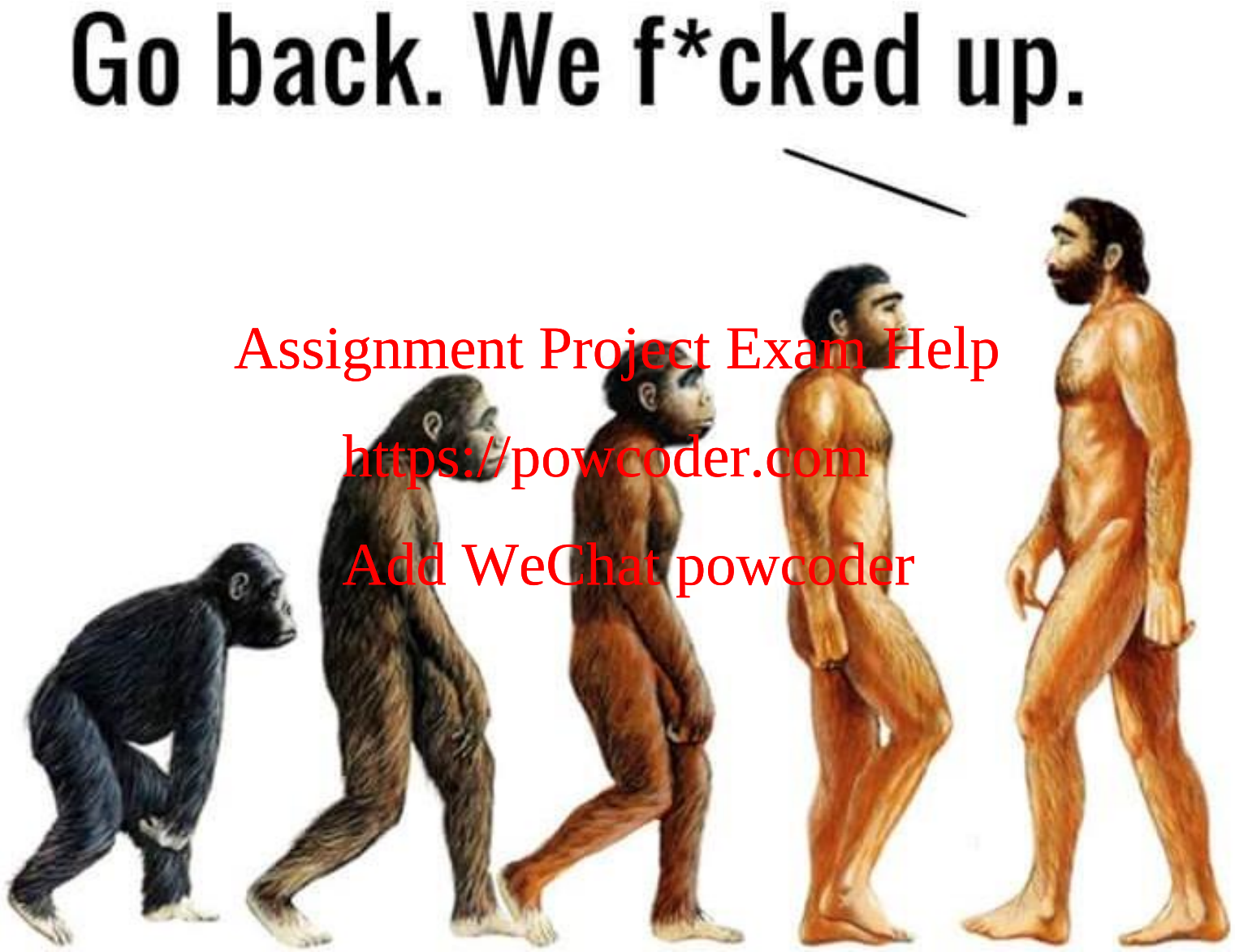






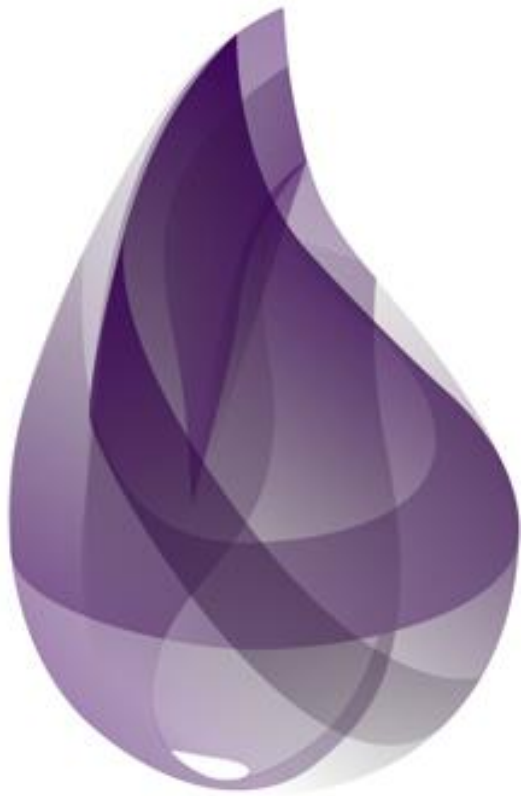
# Functional Programming





# Functional Programming

# Functional Programming



**Higher-order functions:**

- Can return functions or accept them as arguments.



**First class functions:**



- Can be passed as arguments, returned as values.
- Think of them as ***values***, just like integers or floats

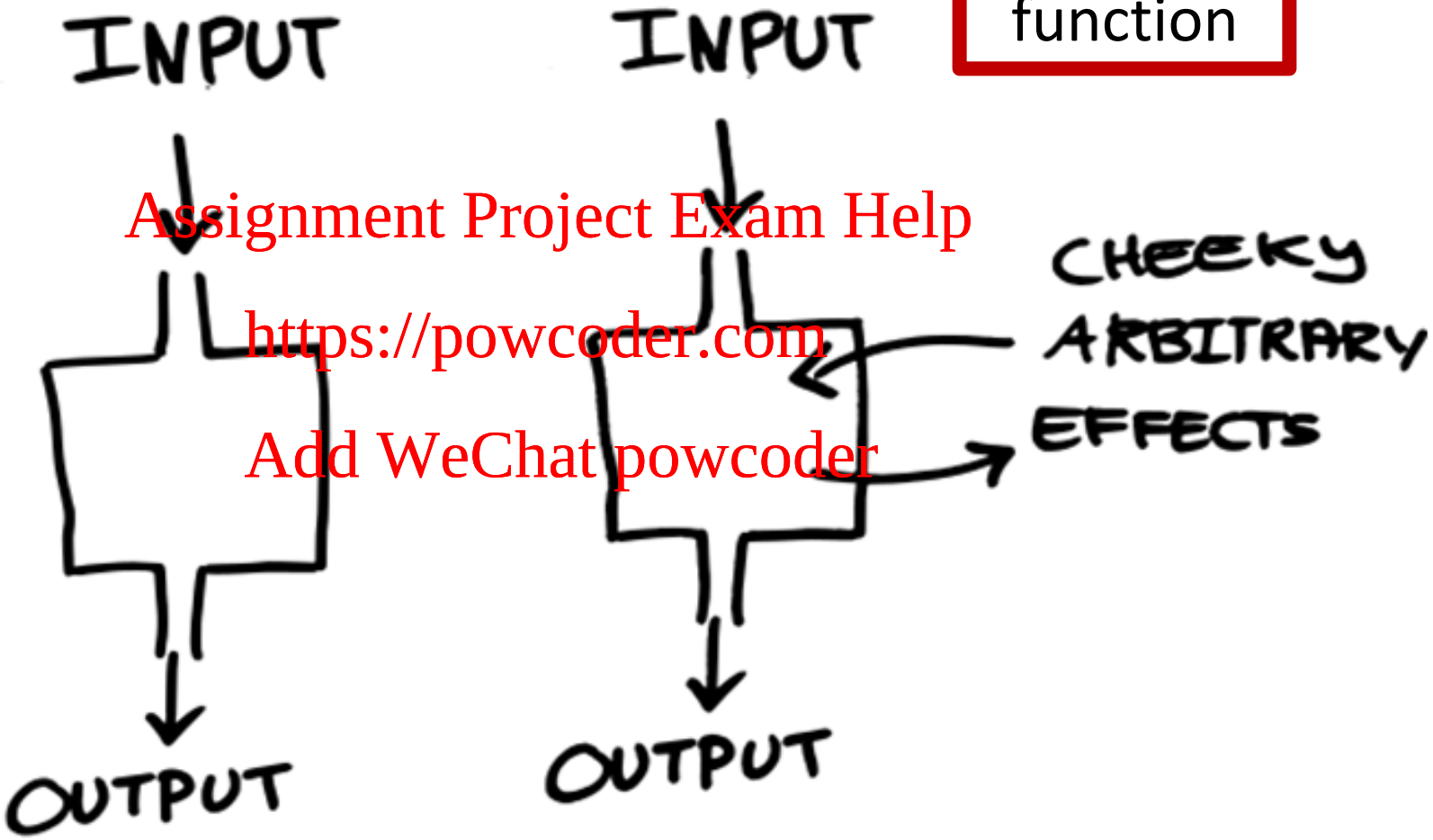


**Pure Functions:**

- Functions that have no side effects. No interaction with world outside of local scope
- Easier to verify correctness, thread-safe when no data dependency is present.

Pure function

Impure function



# Functional Programming

**Strict (eager) VS. non-strict (lazy) evaluation:**

- Strict: evaluate function arguments before invoking the function.
- Lazy: Evaluates arguments if their value is required to invoke the function.



```
Erlang
File  Edit  Options  View  Help

Erlang/OTP 20 [erts-9.2] [64-bit] [smp:8:8] [ds:8:8:10] [async-threads:10]

Interactive Elixir (1.6.5) - press Ctrl+C to exit (type h() ENTER for help)
iex(1)> length [2+1, 3*2, 1/0, 5-4]
** (ArithmeticError) bad argument in arithmetic expression
    :erlang./(1, 0)
iex(1)>
```

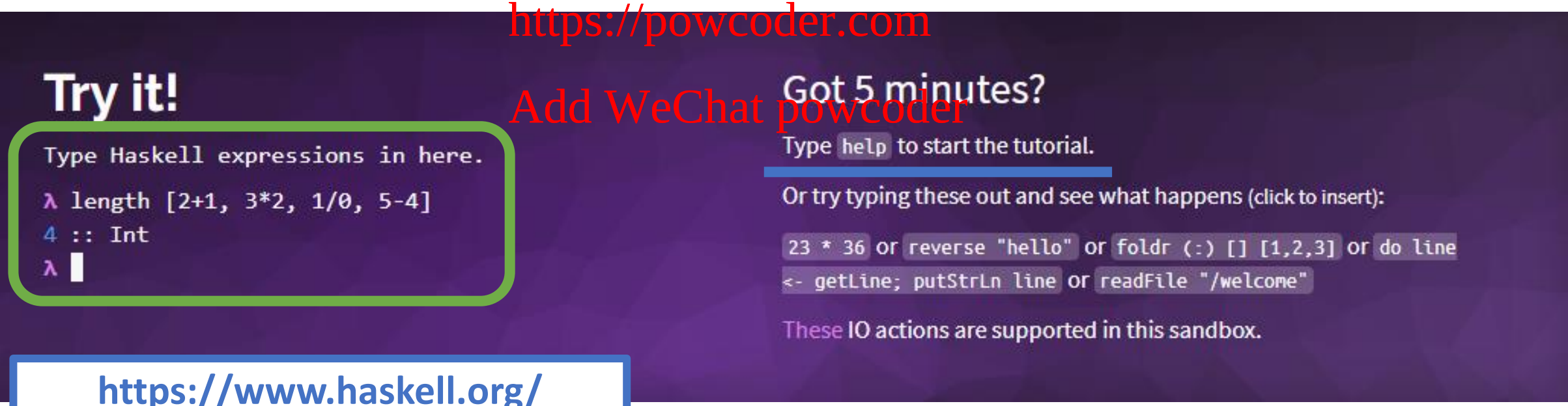
**Elixir largely performs strict evaluation (some exceptions, recall `Stream`, `Range`)**

# Functional Programming

**Strict (eager) VS. non-strict (lazy) evaluation:**

- Strict: evaluate function arguments before invoking the function.
- Lazy: Evaluates arguments if their value is required to invoke the function.






**https://www.haskell.org/**

A great intro to Haskell syntax

# **Haskell:** Functional Programming cranked up to 11

# History

- Named after logician Haskell Curry
- In the late 80s, interest in lazy functional languages was growing
- There was a strong consensus to define an open standard for such languages

# History

- Haskell 1.0 was defined in 1990
  - Continued with version 1.1, 1.2, 1.3, etc.
  - Culminated with *Haskell 98*
- Haskell 2010 was published in July 2010
  - Contained uncontroversial features previously enabled via compiler flags
- Next version being worked on – Haskell 2020
  - Though progress seems to have stalled
  - Perhaps it should be called Haskell 202X

# Features

**Purely Functional:**

- Every function is *pure*
- Even side-effect inducing operations are produced by pure code
- No statements, only expressions
- Cannot mutate variables (local or global)
- Supports pattern matching
- Side effects are handled using *monads*

# Features

**Statically Typed:**

- Every expression has a type
  - Determined at compile time
- Types composing an expressions must match
  - If not, compile error



**Type inference:**

- Types don't have to be written out explicitly
  - Though you can if you want
- They will be inferred at compile time

# Features

**Lazy Evaluation:**

- Functions don't evaluate their arguments
- Control constructs written as functions
- Easy to fuse chains of functions together
- Computation never takes place unless a result is used



**Concurrency:**

- GHC (Haskell compiler) includes high performance parallel garbage collector
- Light-weight concurrency library

# Haskell in Industry?



https://wiki.haskell.org/Haskell_in_industry

# Haskell in industry

Haskell has a diverse range of use commercially, from aerospace and defense, to finance, to web startups, hardware design firms and a lawnmower manufacturer. This page collects resources on the industrial use of Haskell.

- The main user conference for industrial Haskell use is CUFP - the Commercial Users of Functional Programming Workshop.
- The Industrial Haskell Group supports commercial users.
- There is a well-maintained (as of 2018) github repository that collects information on companies using Haskell.
- The commercial Haskell group is a special interest group for companies and individuals interested in commercial usage of Haskell.

The Reddit page 72 would-be commercial Haskell users: what Haskell success stories we need to see has several stories of commercial Haskell users.



## 1 Haskell in Industry



Many companies have used Haskell for a range of projects, including:



- ABN AMRO Amsterdam, The Netherlands

  ABN AMRO is an international bank headquartered in Amsterdam. For its investment banking activities it needs to measure the counterparty risk on portfolios of financial derivatives.

  ABN AMRO's CUFP talk.

- Aetion Technologies LLC, Columbus, Ohio

  Aetion was a defense contractor in operation from 1999 to 2011, whose applications use artificial intelligence. Rapidly changing priorities make it important to minimize the code impact of changes, which suits Haskell well. Aetion developed three main projects in Haskell, all successful. Haskell's concise code was perhaps most important for rewriting: it made it practicable to throw away old code occasionally. DSELs allowed the AI to be specified very declaratively.

  Aetion's CUFP talk.

- Alcatel-Lucent

  A consortium of groups, including Alcatel-Lucent, have used Haskell to prototype narrowband software radio systems, running in (soft) real-time.

**Notable companies that use or have used Haskell:**

- Nvidia
- AT&T
- Ericsson
- Facebook
- Google
- Intel
- Microsoft

Typically Haskell is used on specialized internal projects or research. Not necessarily company-wide.

# Installing Haskell:



https://www.haskell.org/

# Haskell

An advanced, purely functional programming language

Declarative, statically typed code.

```
primes = filterPrime [2..]
  where filterPrime (p:xs) =
          p : filterPrime [x | x <- xs, x `mod` p /= 0]
```



## Try it!

Type Haskell expressions in here.

λ

Neat!

## Got 5 minutes?

Type `help` to start the tutorial.

Or try typing these out and see what happens (click to insert):

`23 * 36` or `reverse "hello"` or `foldr (:) []` `[1,2,3]` or `do line <- getLine; putStrLn line` or `readFile "/welcome"`

These IO actions are supported in this sandbox.

Downloads Community Documentation News

Hask

An advanced, purely functional programm

Declarative, statically typed code.

```
primes = filterPrime [2..]
  where filterPrime (p:xs) =
          p : filterPrime [x | x <- xs, x `mo
```

# Haskell Platform

## What it is

The Haskell Platform is a self-contained, all-in-one installer. After download, you will have everything necessary to build Haskell programs against a core set of useful libraries. It comes in both minimal versions with tools but no libraries beyond GHC core, or full versions, which include a broader set of globally installed libraries.





## What you get

- The Glasgow Haskell Compiler
- The Cabal build system, which can install new packages, and by default fetches from Hackage, the central Haskell package repository.
- the Stack tool for developing projects
- Support for profiling and code coverage analysis
- 35 core & widely-used packages



## How to get it

The Platform is provided as a single installer, and can be downloaded at the links below.

- Linux
- OS X
- Windows

Repl.it - CCPS506_Haskell

repl.it/@AlexUfkes/CCPS506Haskell#main.hs

AlexUfkes / CCPS506_Haskell

Share

Files

main.hs

main.hs

```haskell
main = putStrLn "Hello world!"
```

Console

Shell

```
GHCi, version 8.6.5
Hello world!
```

Filters

Best match

WinGHCi
Desktop app

Search suggestions

- wingh - See web results
- wingham
- winghouse
- winghart's
- wingham ontario
- winghaven mo
- wingham free press
- winghaven
- winghouse tampa

wingh

WinGHCi

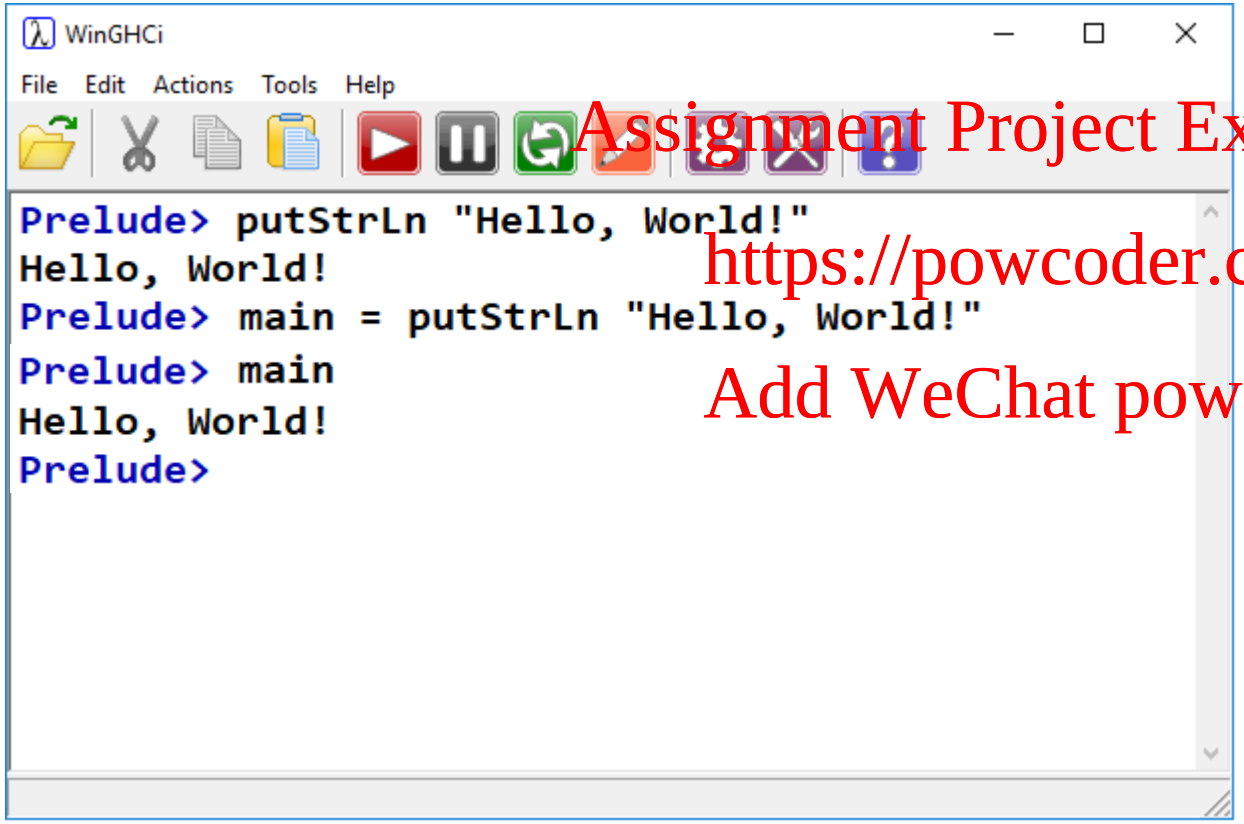
File Edit Actions Tools Help

```
GHCi, version 8.4.2: http://www.haskell.org/ghc/  :? for help
Prelude>
```



- Interactive shell, just like Elixir.
- Haskell's is better!

# Hello, World!



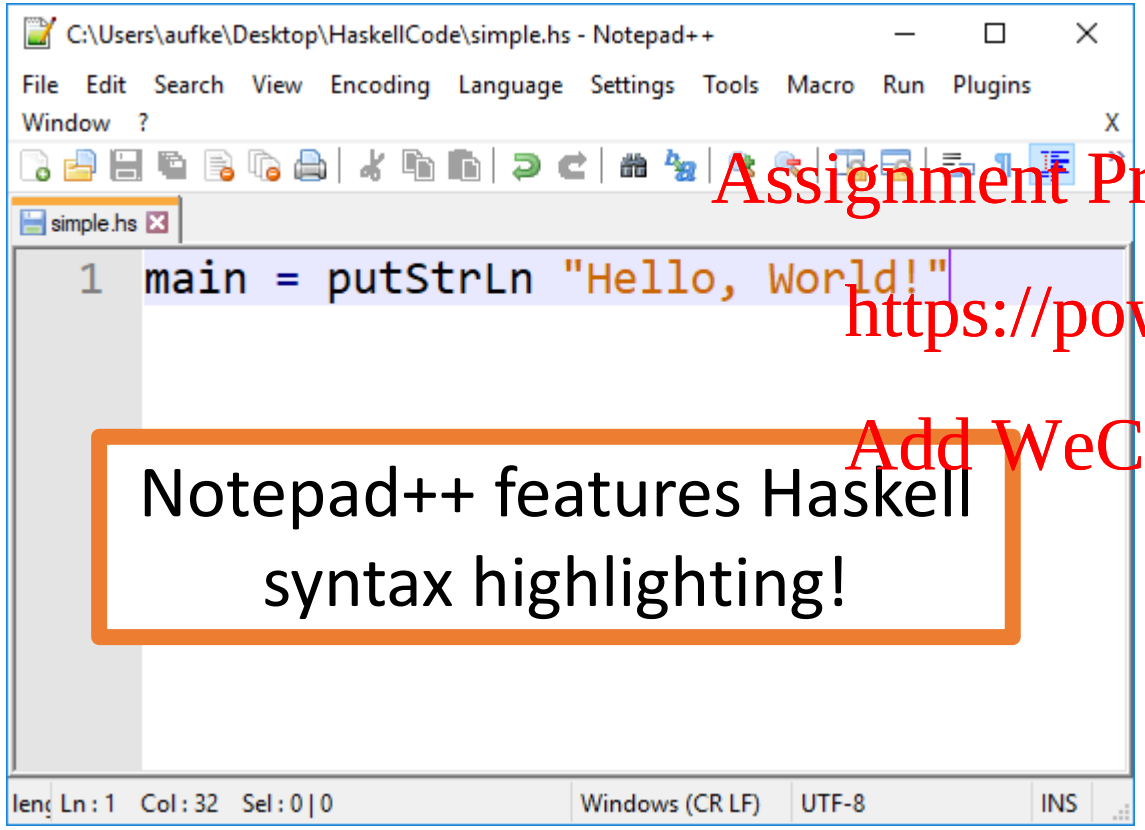



putStrLn == System.out.println()
putStr == System.out.print()

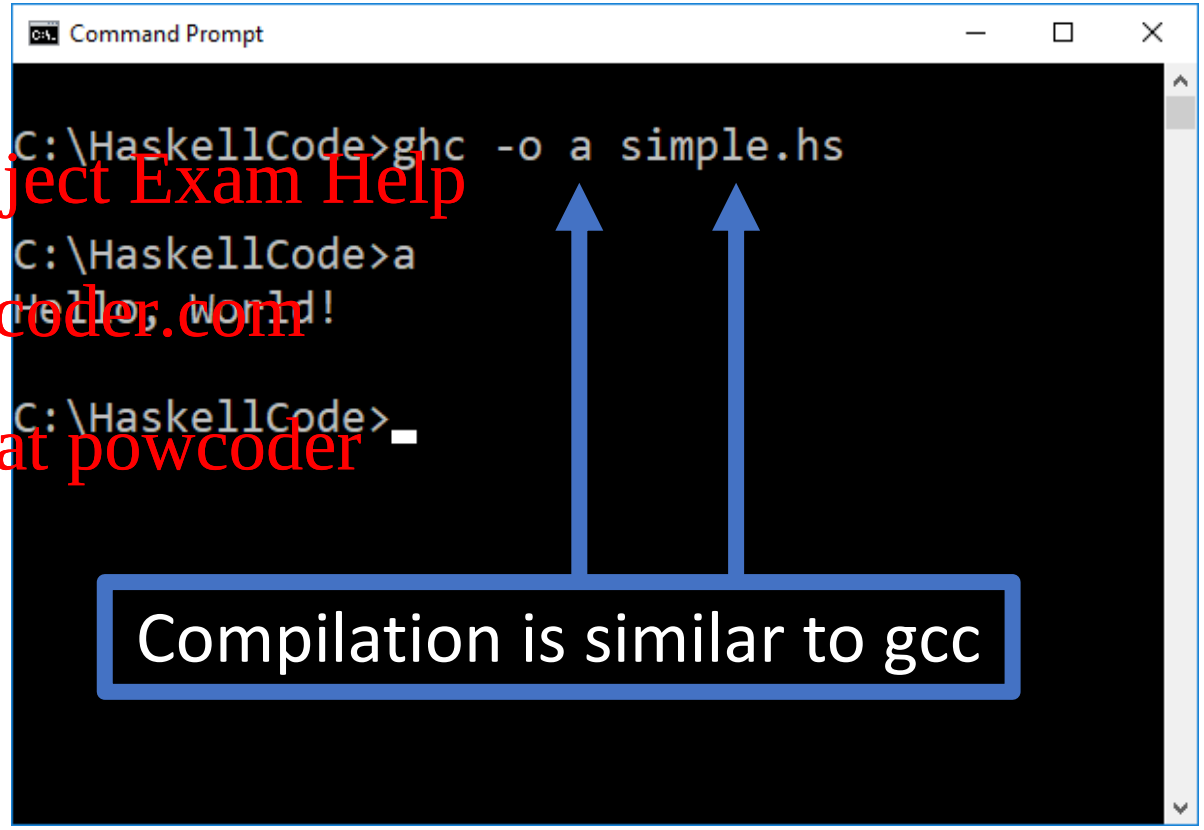
- Define a main function.
- When executing a Haskell program, main is the entry point
- Just like C or Java

Execute main function

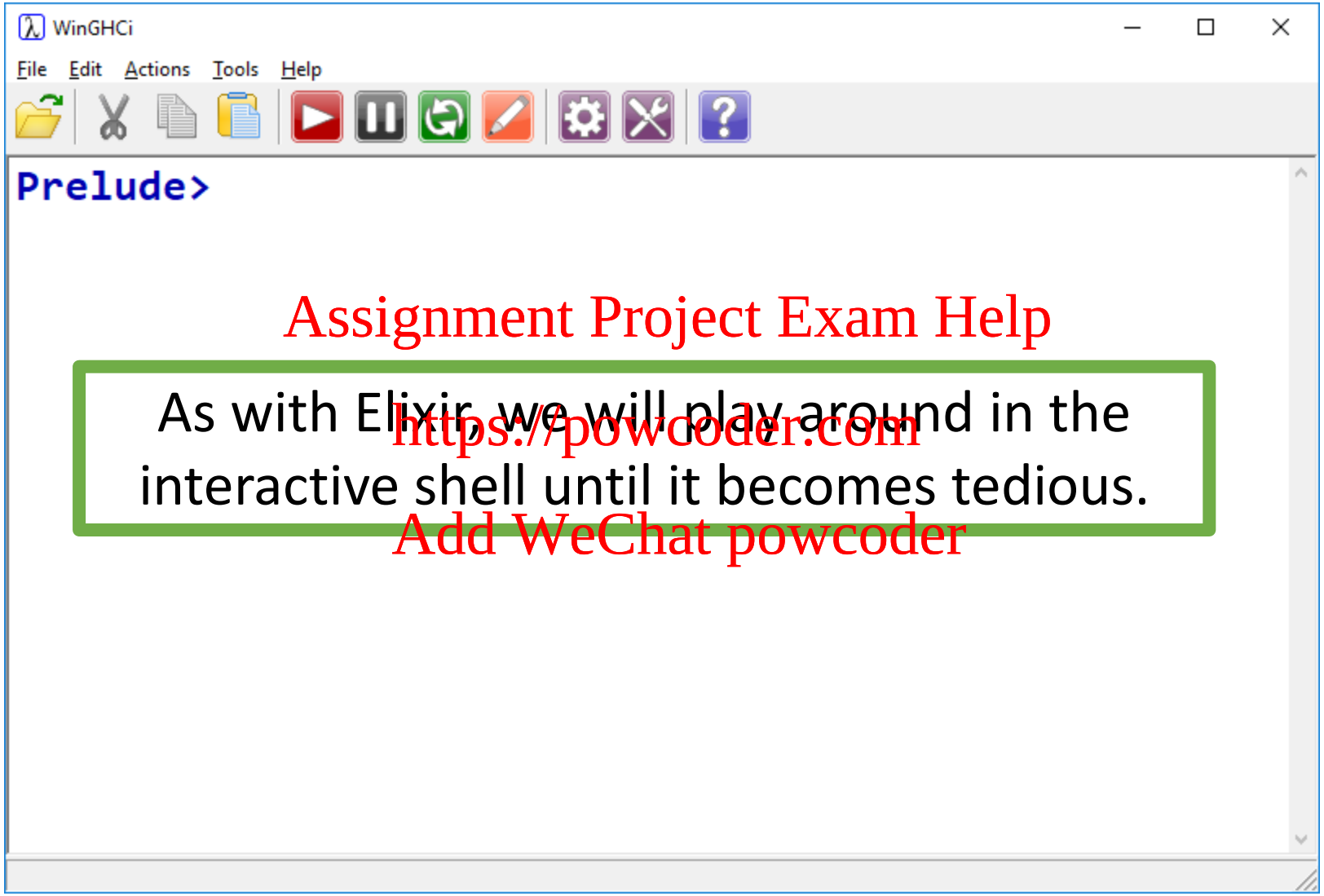
# Compiling Haskell




Notepad++ features Haskell syntax highlighting!



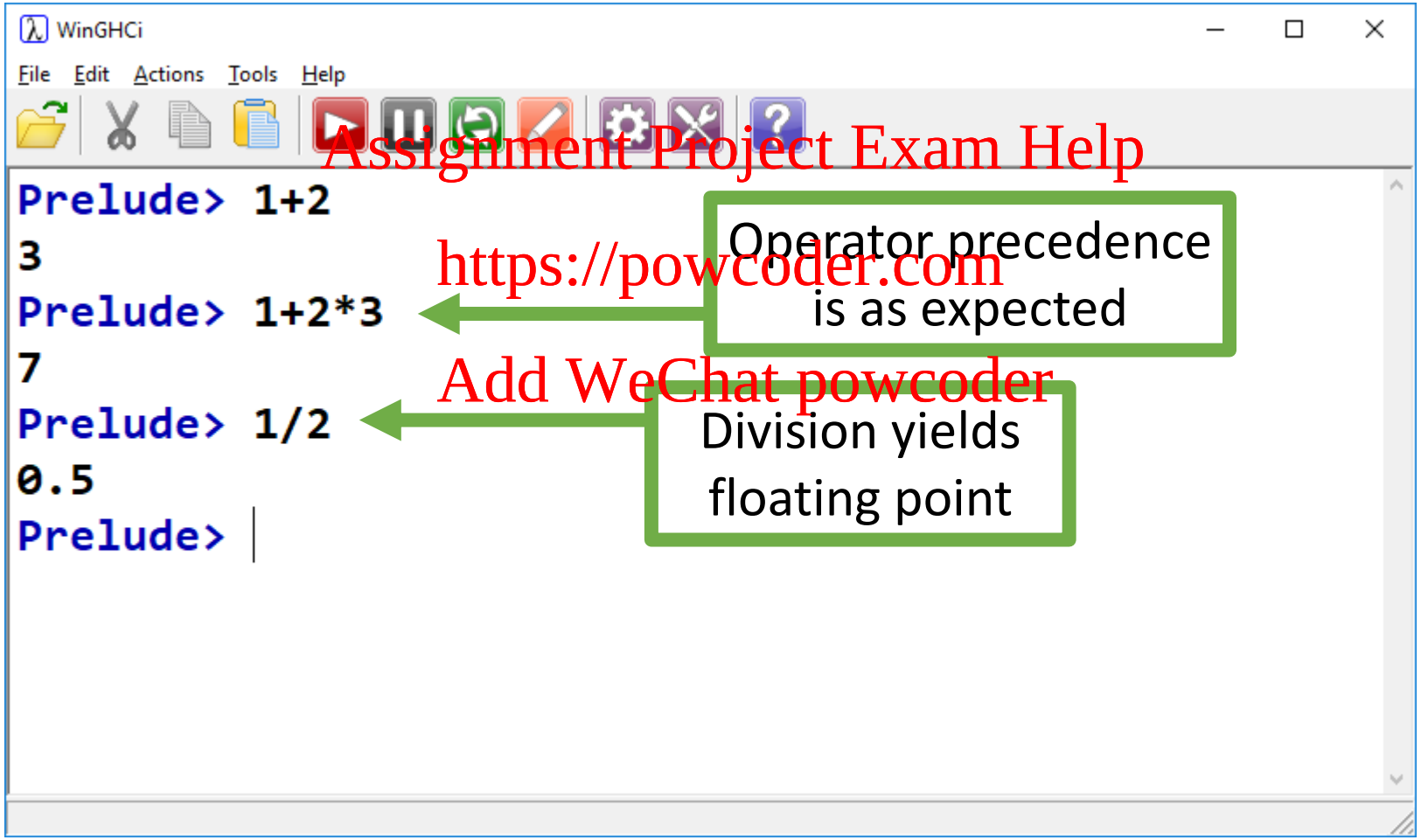

Compilation is similar to gcc



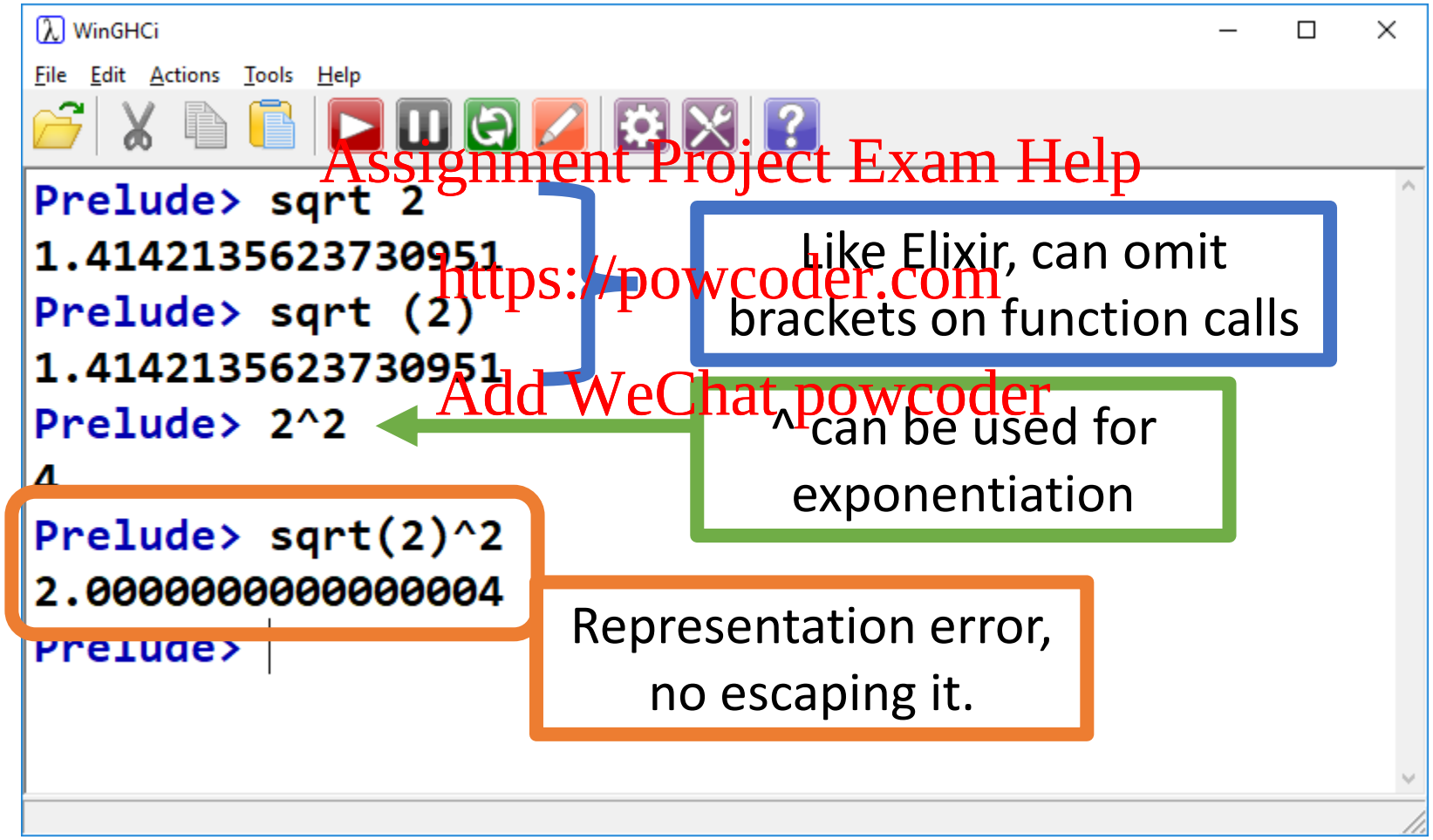



As with Elixir, we will play around in the interactive shell until it becomes tedious.

# Literals & Arithmetic



# Literals & Arithmetic



# Tuples

WinGHCi

File Edit Actions Tools Help

```
Prelude> (3, 5)
(3,5)
Prelude> (5, "hello")
(5,"hello")
Prelude> fst (5, "hello")
5
Prelude> snd (5, "hello")
"hello"
Prelude> (1, 2, 3, "Hello", "World")
(1,2,3,"Hello","World")
Prelude>
```



- Like Elixir, Haskell supports tuples.
- They need not contain the same types.





There are built in functions for accessing first and second elements. Great for coordinates.

WinGHCi

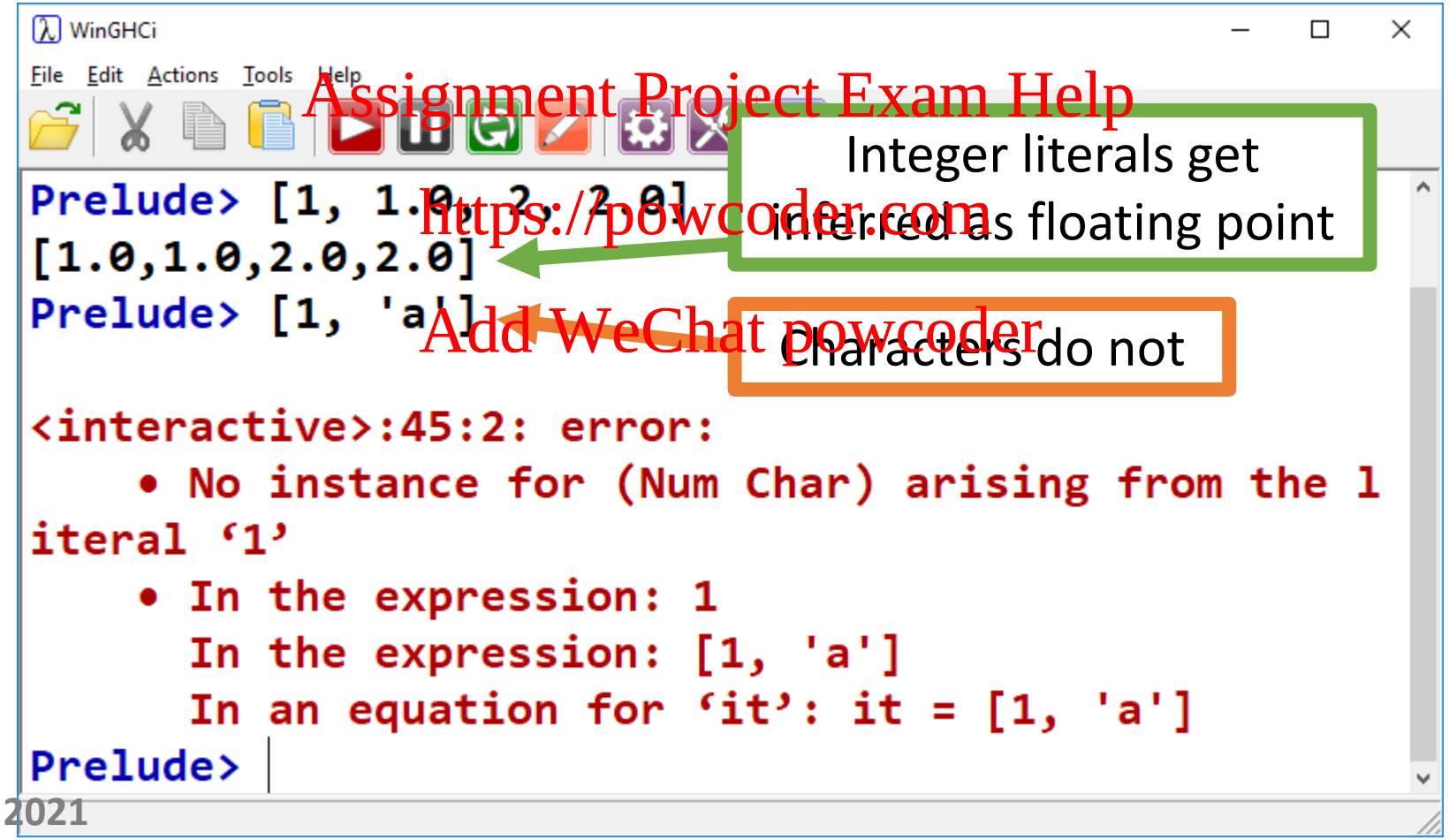
File Edit Actions Tools Help

```
Prelude> fst (1, 2, 3)

<interactive>:35:5: error:
    • Couldn't match expected type ‘(a, b0)’
                  with actual type ‘(Integer, Integ
er, Integer)’
    • In the first argument of ‘fst’, namely ‘(1, 2
, 3)’
      In the expression: fst (1, 2, 3)
      In an equation for ‘it’: it = fst (1, 2, 3)
    • Relevant bindings include it :: a (bound at <
interactive>:35:1)
Prelude>
```

**`fst`** and **`snd`** only work on pair tuples!

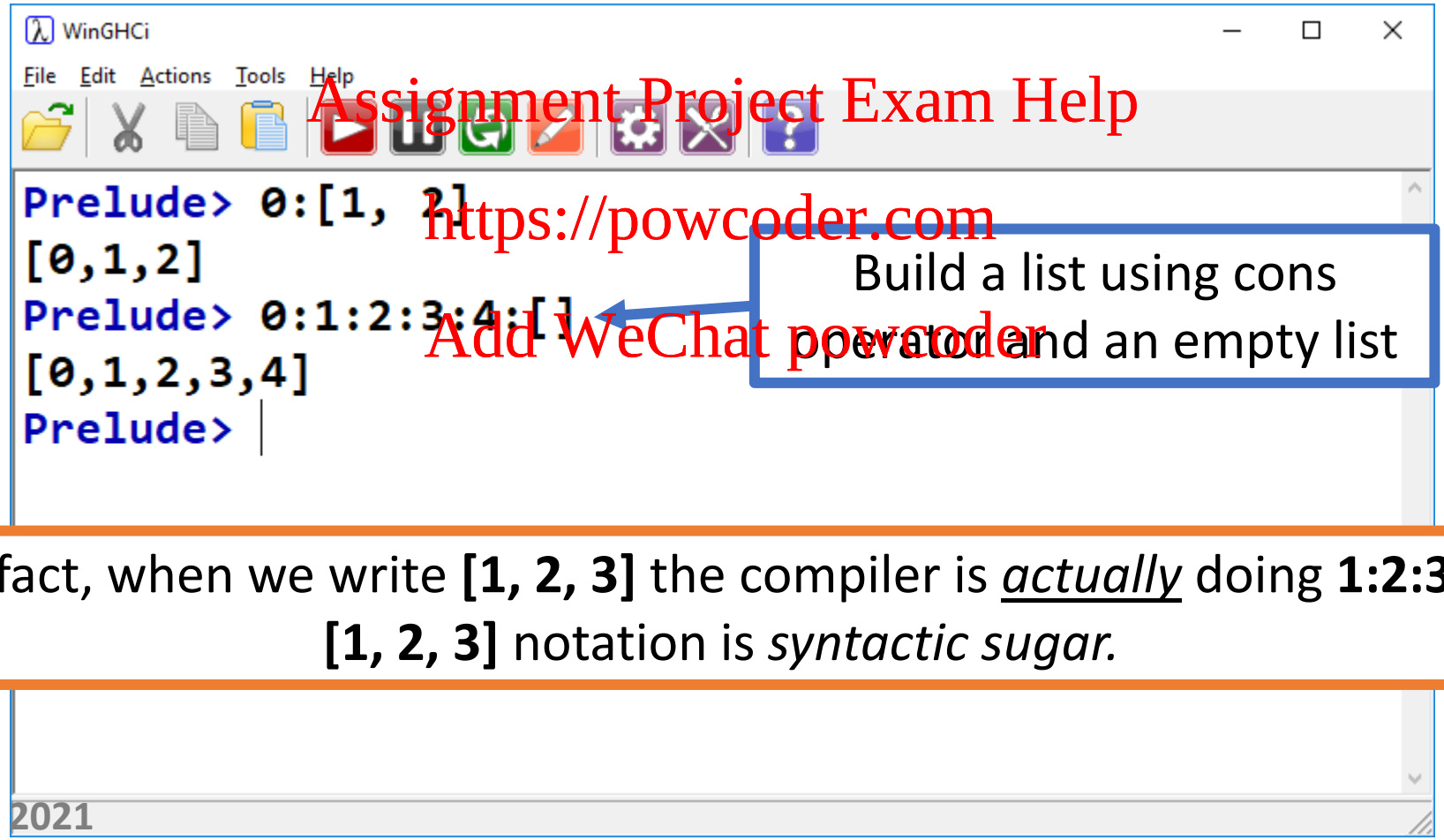
# Lists

Must be ***homogeneous***:



# Lists

Elements can be added to the *beginning* of a list with the **cons** ( : ) operator

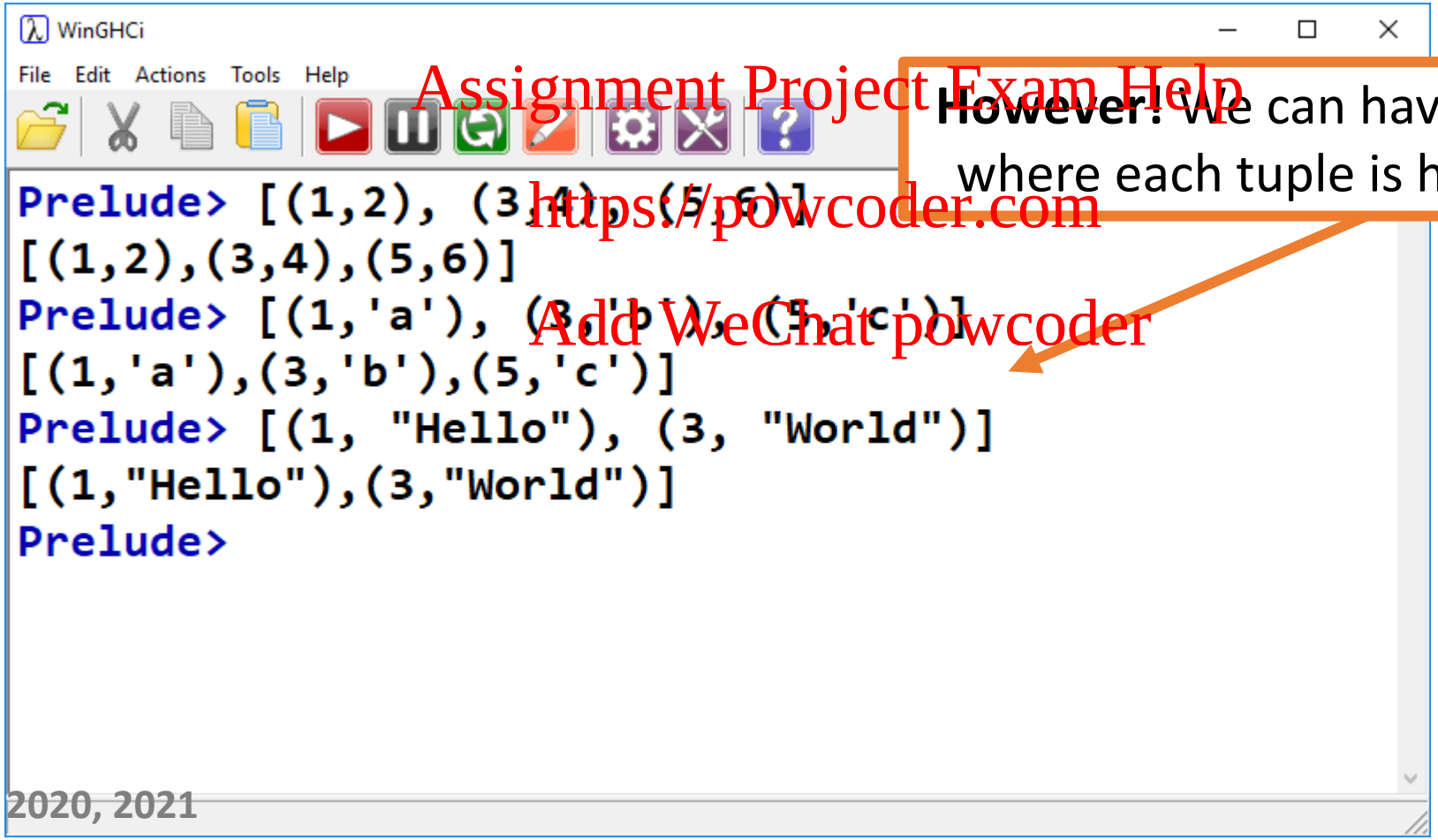





In fact, when we write **[1, 2, 3]** the compiler is *actually* doing **1:2:3:[]**
**[1, 2, 3]** notation is *syntactic sugar.*

# Lists & Tuples

Tuples can be heterogeneous, lists must be homogeneous.




**However!** We can have lists of tuples, where each tuple is heterogeneous.

# Lists & Tuples

Tuples can be heterogeneous, lists must be homogeneous.

WinGHCi

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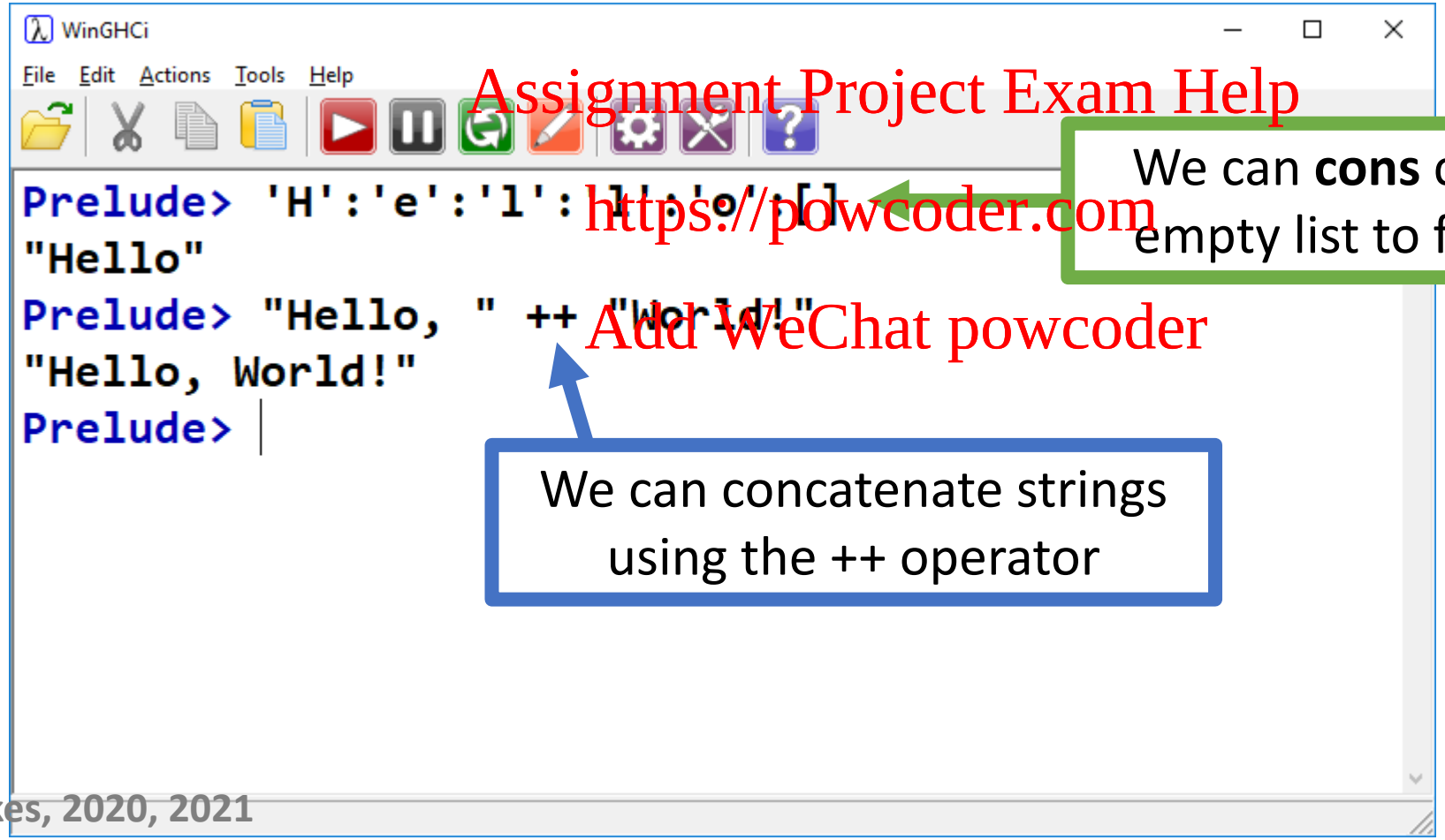
```
Prelude> [(1, "Hello"), (2, "World")]
[(1,"Hello"),(2,"World")]
Prelude> [(1, "Hello"), (2, 3.4)]

<interactive>:67:20: error:
    • Could not deduce (Fractional [Char])
      arising from the literal ‘3.4’
      from the context: Num a
        bound by the inferred type of it :: Num a => [(a, [Char])]
        at <interactive>:67:1-24
    • In the expression: 3.4
      In the expression: (2, 3.4)
      In the expression: [(1, "Hello"), (2, 3.4)]
Prelude>
```

**However #2:**

- In a list of tuples, each tuple must have the same format:

# Strings

Strings are simply lists of chars:



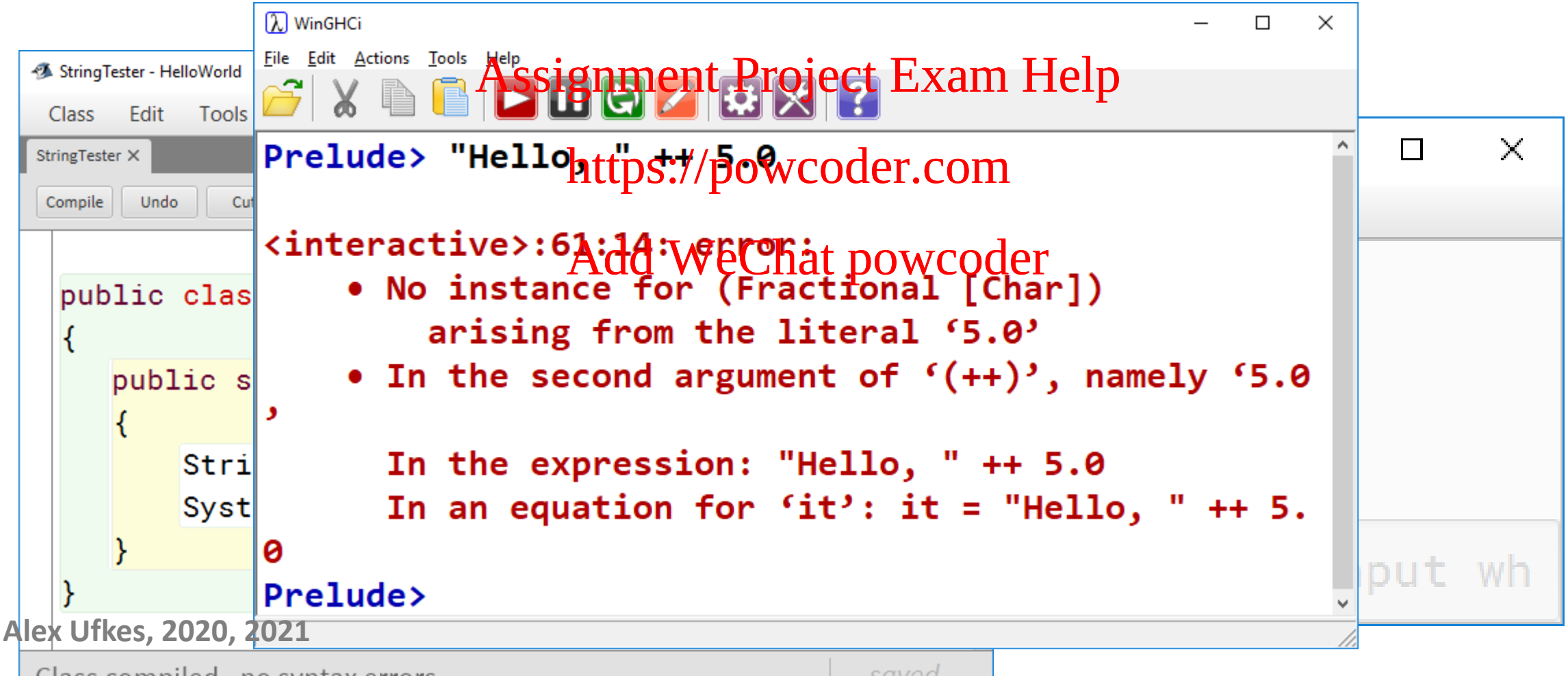



We can **cons** chars into an empty list to form a string

We can concatenate strings using the ++ operator

# Strings

Concatenate multiple types? Java lets us…



# Strings

**`show()`** and **`read()`** functions

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```
Prelude> "This course is " ++ "CCPS" ++ show(506)
"This course is CCPS506"
Prelude> read "506" - 6
500
Prelude> read "Hello" + 1
*** Exception: Prelude.read: no parse
Prelude>
```

Convert non-string argument to string

Read numeric value from a string (like *sscanf* in C)

Error when no numeric value is present

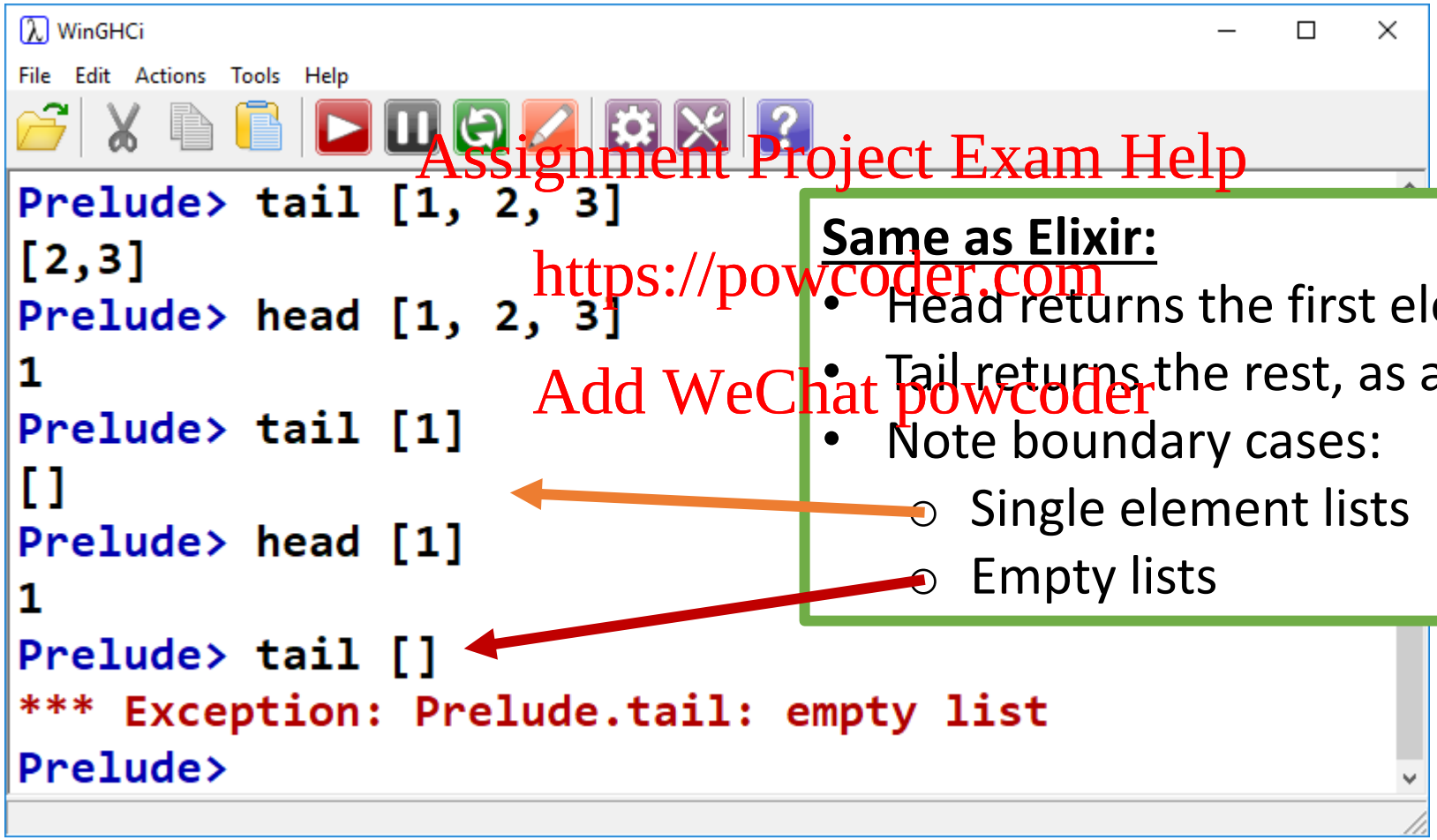
# Operations on Lists

- In functional programming, computation is done in large part by operating on lists.
- We saw the **`hd`**, **`tl`**, **`|`**, and **`Enum`** in Elixir.
- Haskell has a similar set of operations.



Three primary list-processing functions: **`map`**, **`filter`**, **`foldr`** (and **`foldl`**)

# Head & Tail



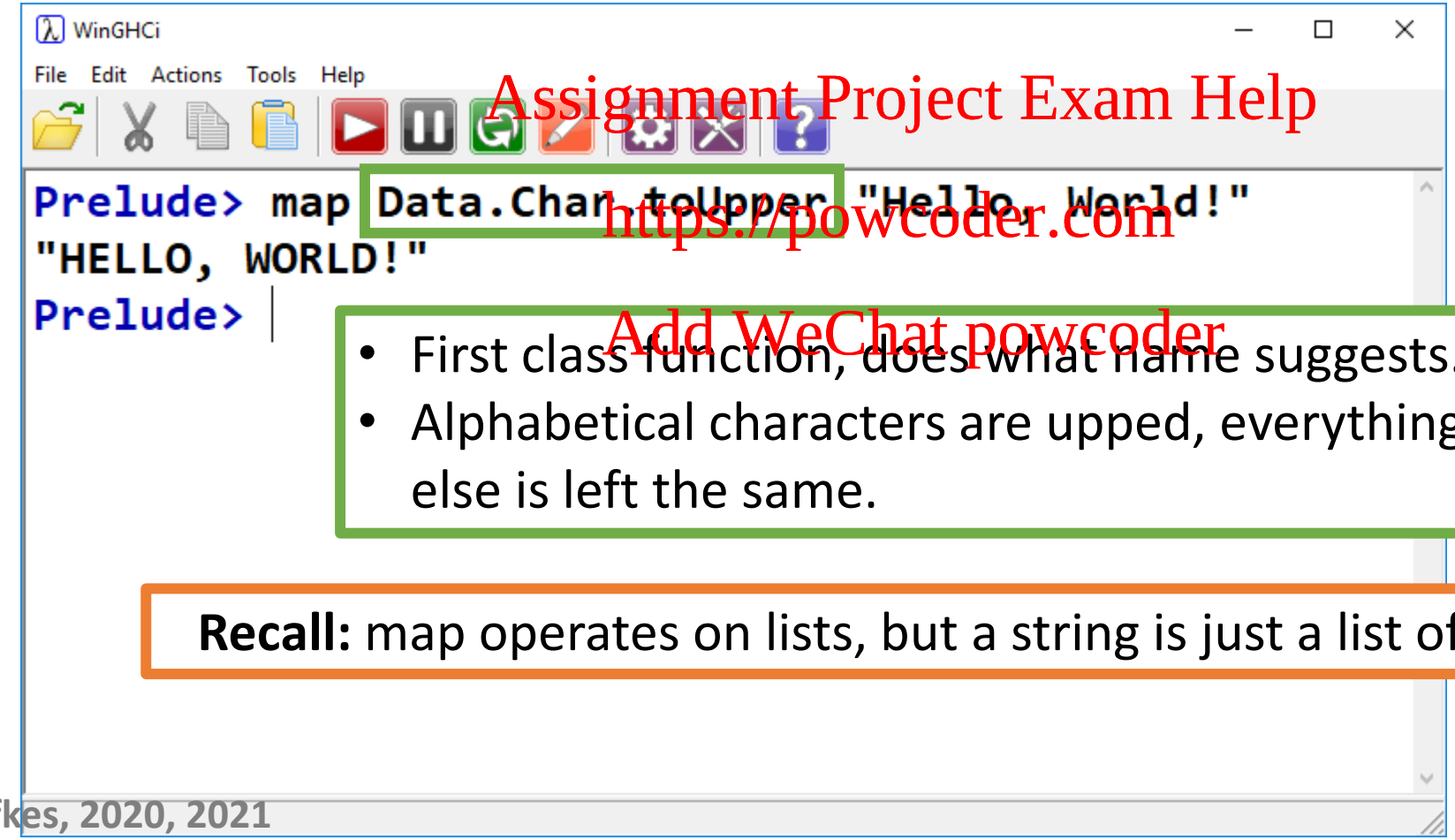



**Same as Elixir:**

- Head returns the first element
- Tail returns the rest, as a list
- Note boundary cases:
  - Single element lists
  - Empty lists

# map

Similar to Elixir's **`Enum.map`**



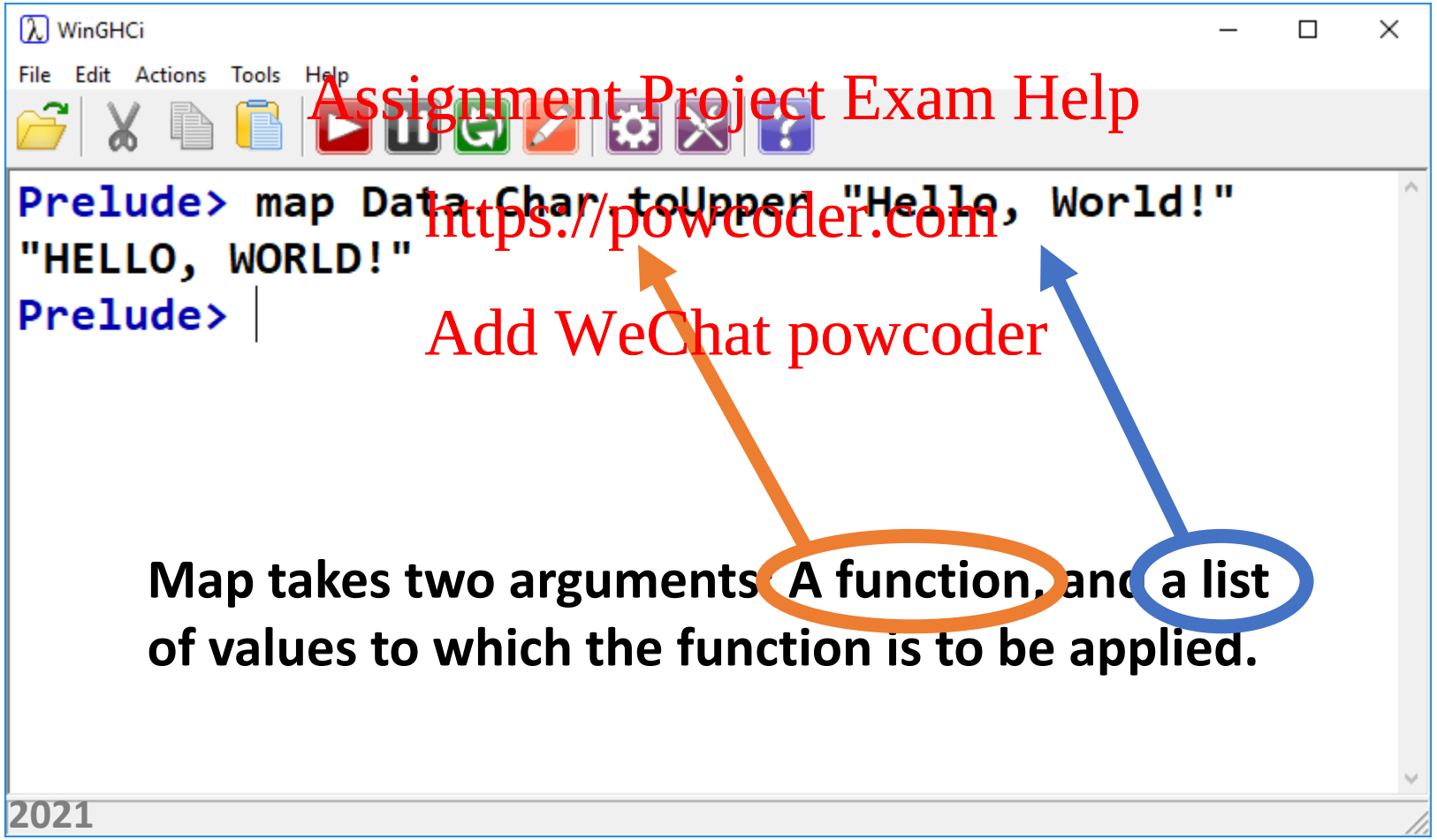



- First class function, does what name suggests.
- Alphabetical characters are upped, everything else is left the same.

**Recall:** map operates on lists, but a string is just a list of characters

# map

Similar to Elixir's **`Enum.map`**

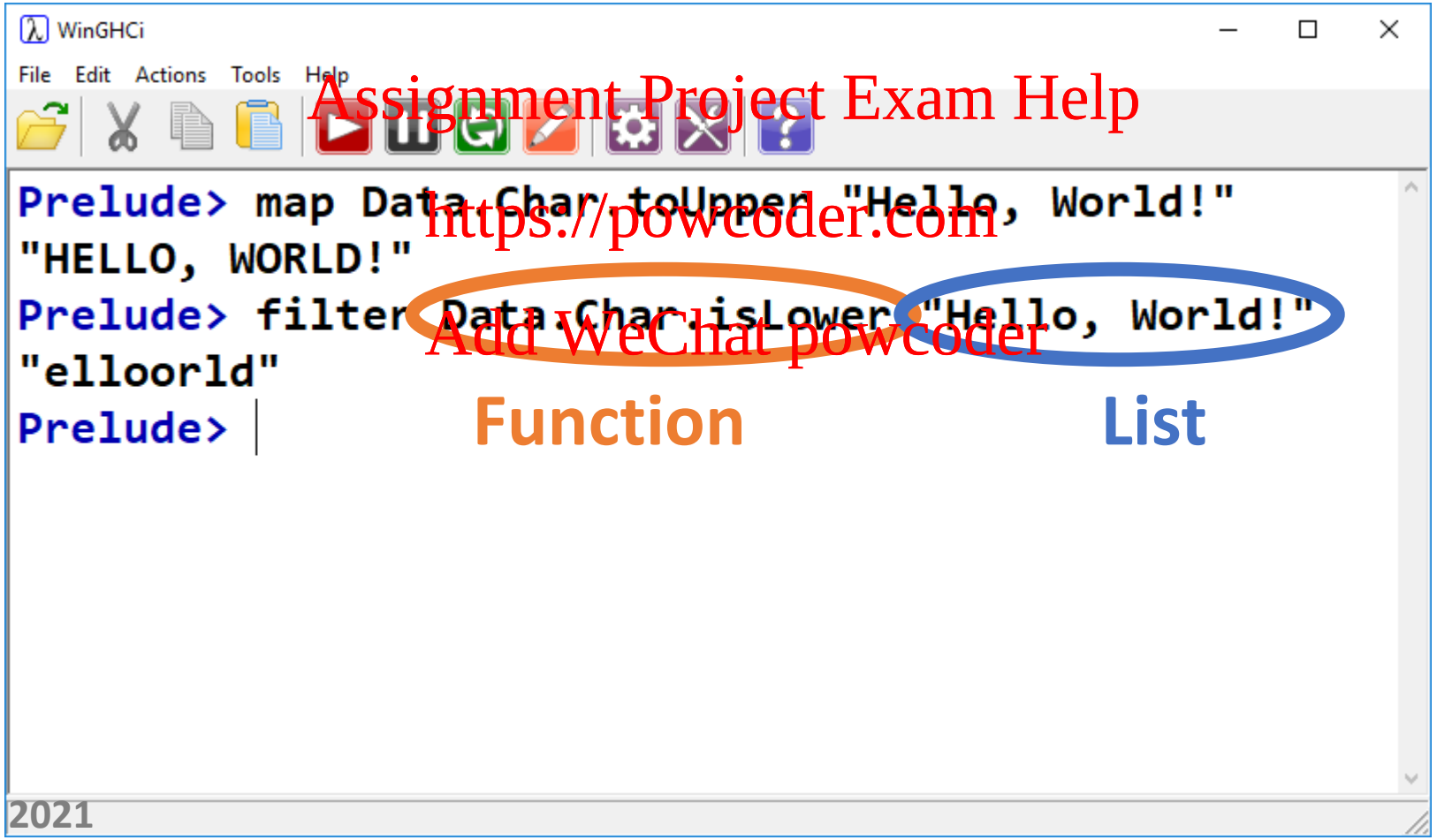





**Map takes two arguments: A function, and a list of values to which the function is to be applied.**

# filter

"Remove" items from a list based on some criteria:



# foldl, foldr

Replaces the cons operator with some other function. This takes some explaining.



Recall that the list:



```
[1, 2, 3, 4, 5]
```



Is actually seen as:

```
1:2:3:4:5:[]
```

By the compiler.

# `foldl, foldr`

Replaces the cons operator with some other function. This takes some explaining.



Recall that the list:



```
[1, 2, 3, 4, 5]
```



Is actually seen as:

```
1:2:3:4:5:[]
```

By the compiler.

- **`foldr`** in effect replaces the cons operator with another function of our choosing.
- This is similar to **`Enum.reduce`** in Elixir.
- The empty list is replaced with some initial value.

# foldl, foldr

Replaces the cons operator with some other function. This takes some explaining.

- **foldr** in effect replaces the cons operator with another function of our choosing.
- This is similar to **Enum.reduce** in Elixir.
- The empty list is replaced with some initial value.



```
foldr (+) 0 [1, 2, 3, 4, 5]
```

Three arguments: **function**, **initial value**, **list**

# foldl, foldr

Replaces the cons operator with some other function. This takes some explaining.

```
foldr (+) 0 [1, 2, 3, 4, 5]
```





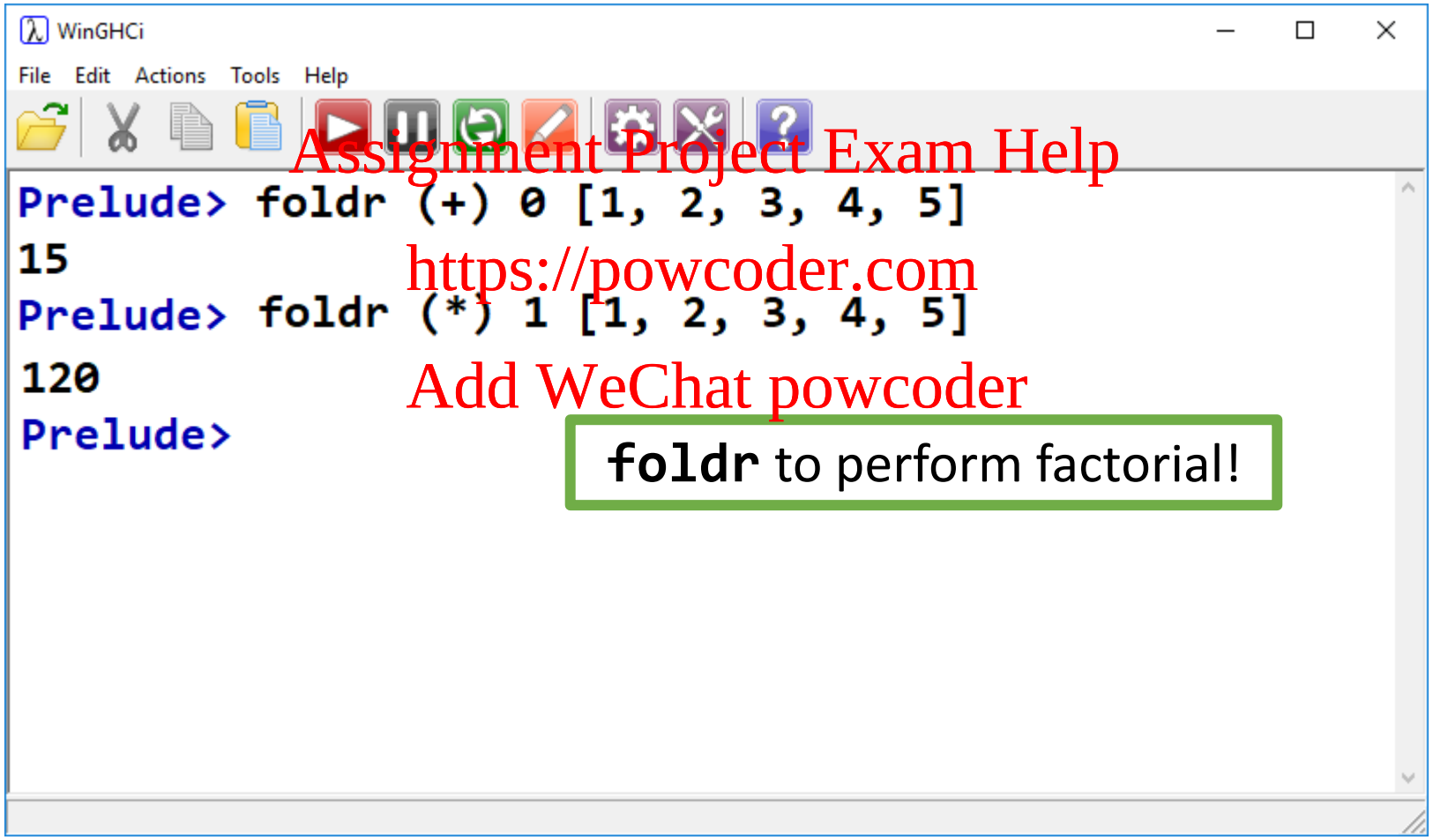
```
foldr (+) 0 1:2:3:4:5:[]
```



```
1 + 2 + 3 + 4 + 5 + 0
```

```
15
```

# foldl, foldr






**foldr** to perform factorial!

# `foldl` VS `foldr`

**`foldr`** is *right associative*. Meaning:

```
foldr (+) 0 [1, 2, 3, 4, 5]
```





```
1 + 2 + 3 + 4 + 5 + 0
```



**Is actually:**

```
(1 + (2 + (3 + (4 + (5 + 0)))))
```

Doesn't matter for addition, but subtraction…

# `foldl` VS `foldr`

**`foldr`** is *right associative*. Meaning:

```
foldr (-) 1 [4, 8, 5]
```





```
4 - 8 - 5 - 1
```



**Is actually:**

```
(4 - (8 - (5 - 1 )))
```

```
0
```

# `foldl` VS `foldr`

**`foldl`** is *left associative*. Meaning:

```
foldl (-) 1 [4, 8, 5]
```





```
1 - 4 - 8 - 5
```

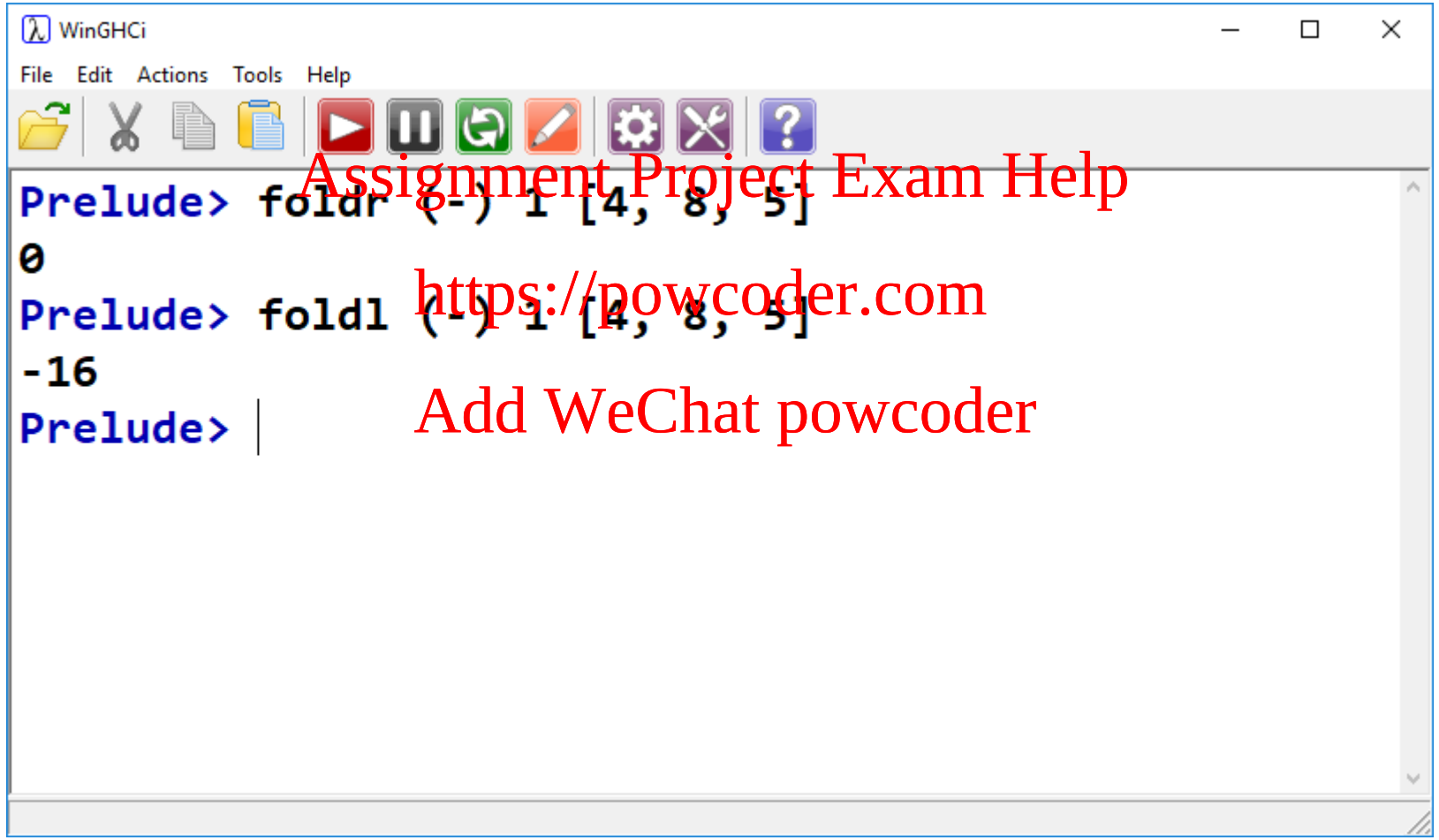


**Is actually:**

```
(((1 - 4) - 8) - 5)
```

```
-16
```

# foldl VS foldr



# List Generation

Syntactic sugar:

List declaration: `list = [1, 2, 3, 4, 5, 6, 7, 8, 9]`

Can be written: `list = [1..9]`

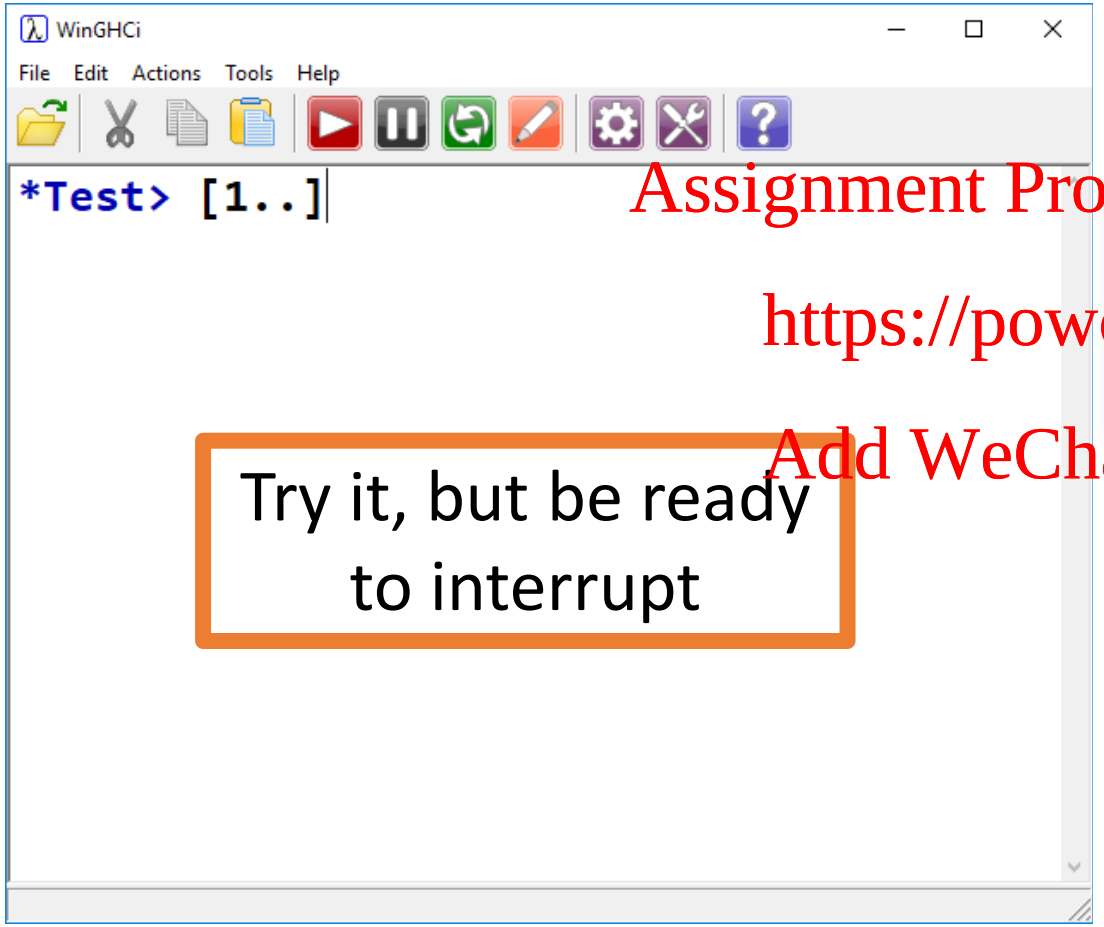
Specify interval: `list = [1,3..9]`

`= [1,3,5,7,9]`

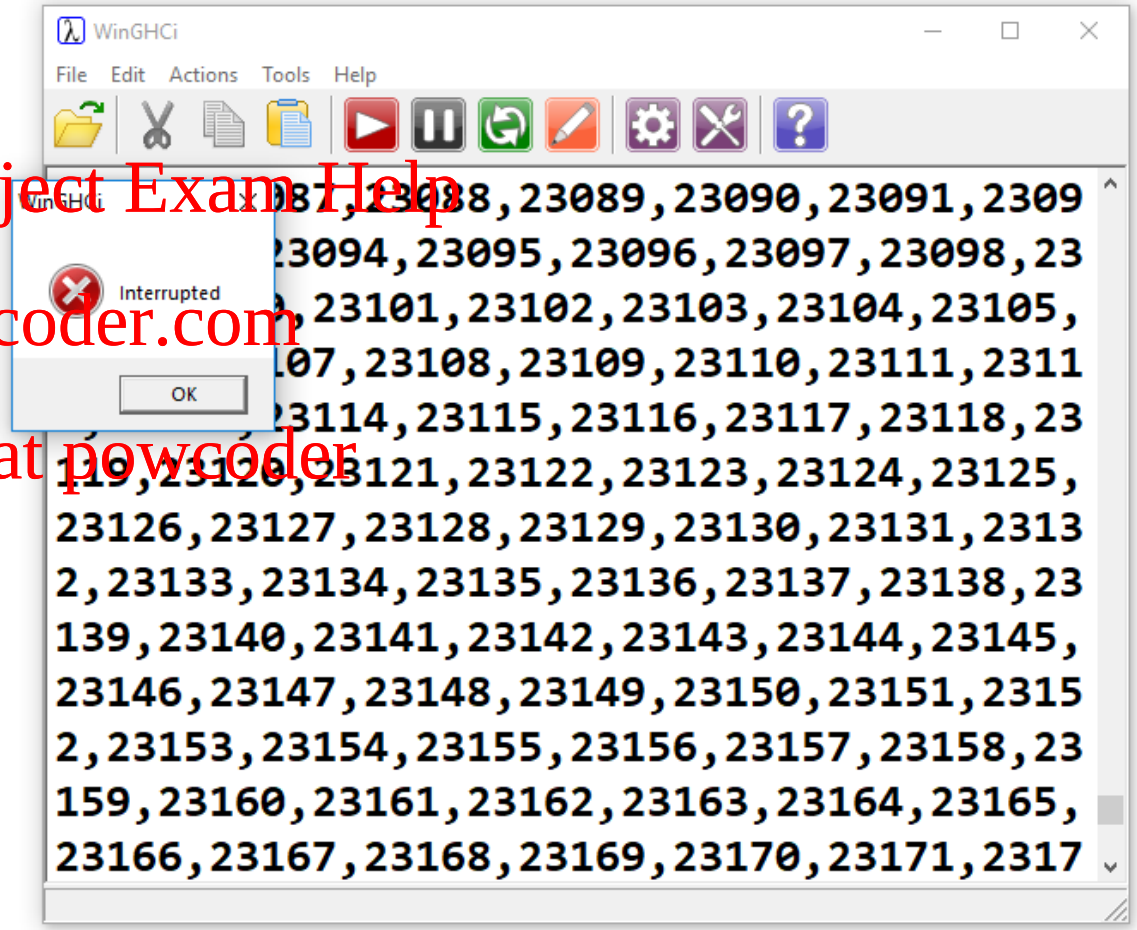


Interval is discerned from difference between first two elements

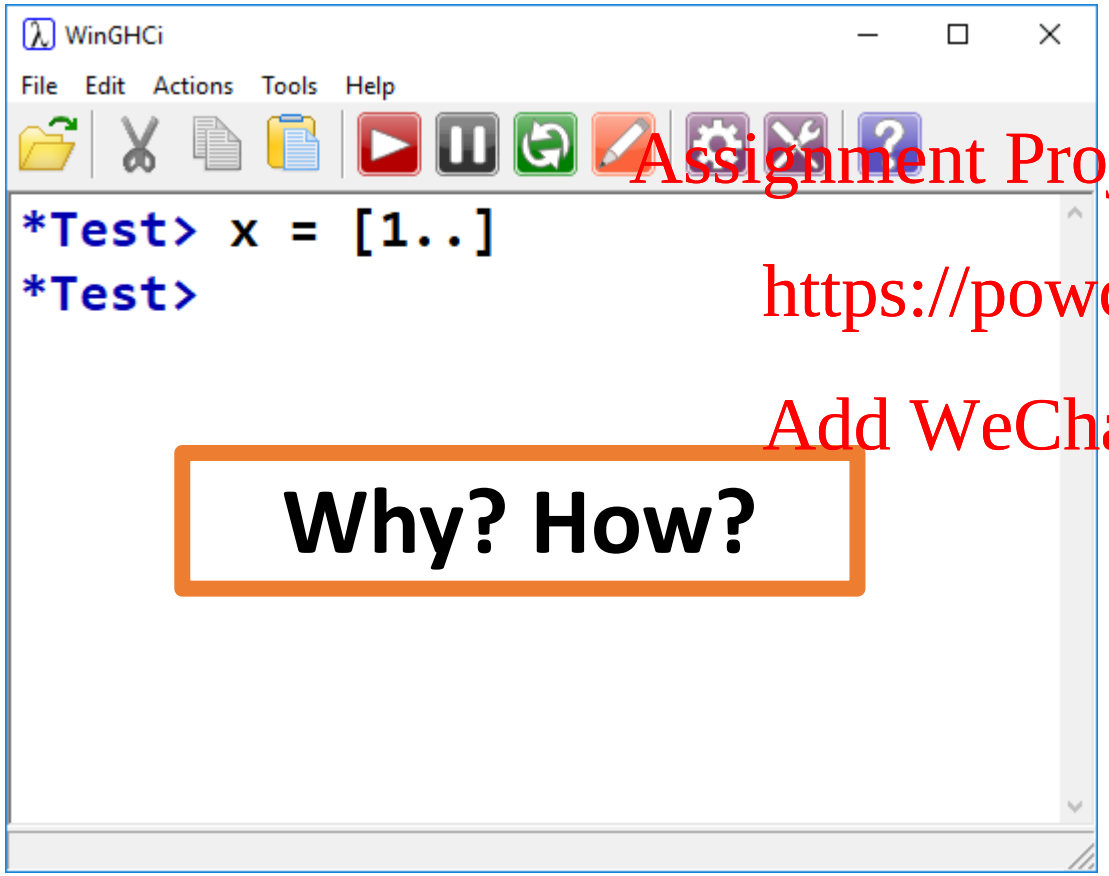
# Infinite Lists?




Try it, but be ready to interrupt



# Infinite Lists?



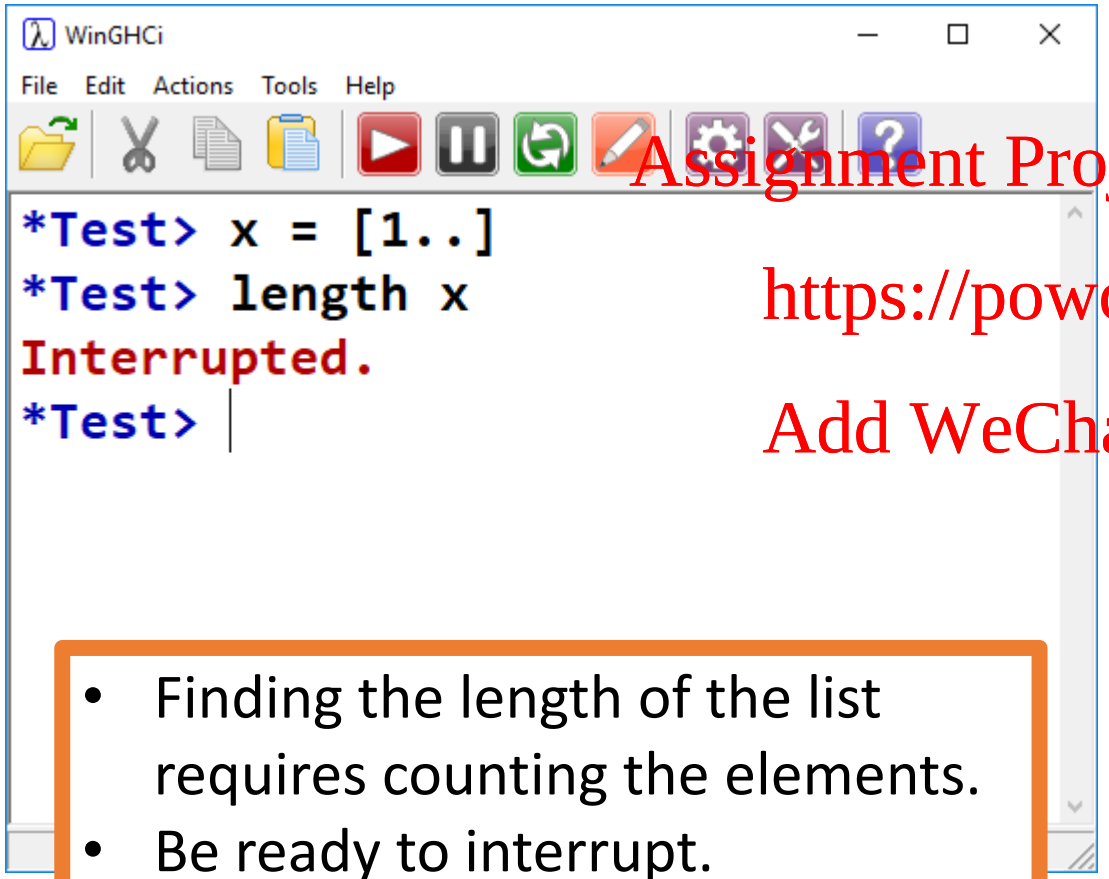

**Why? How?**

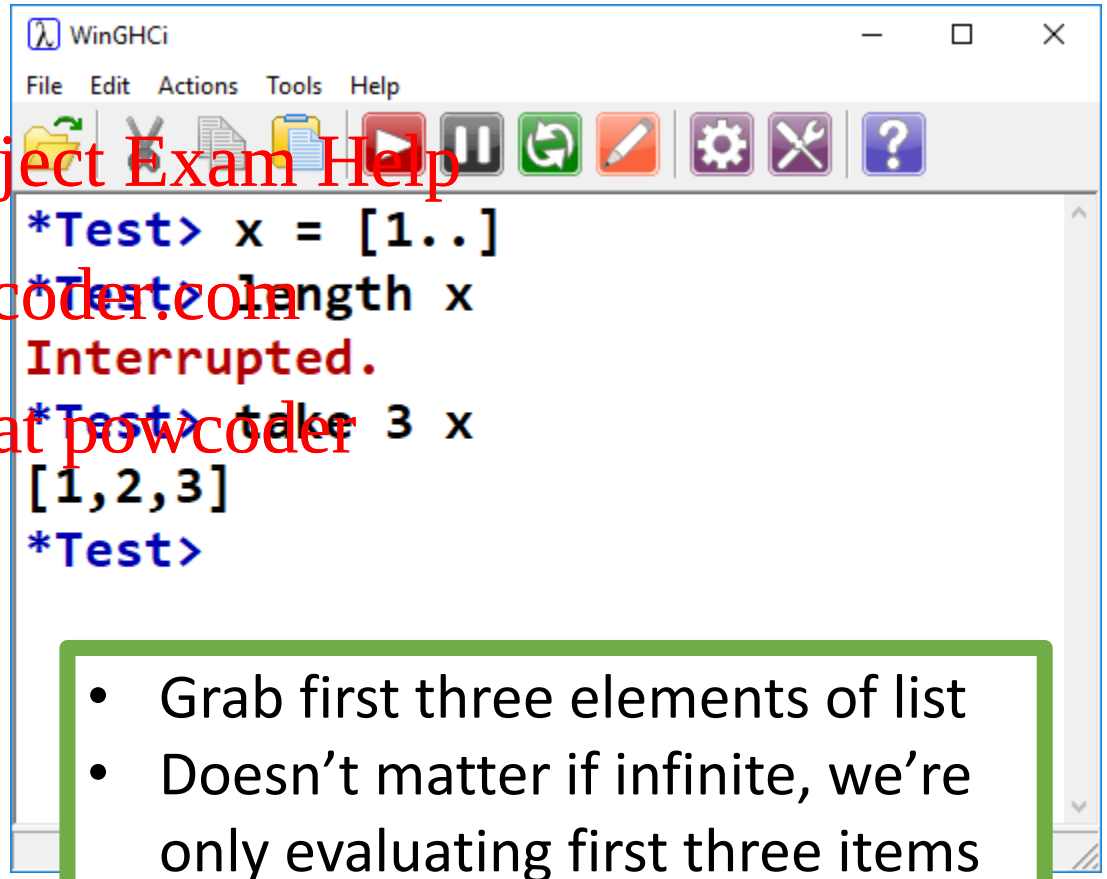


**Haskell is lazy!**

- We bind x to the expression to generate an infinite list.
- We don't have to *evaluate* this list to do so!
- Displaying the list, however, requires evaluation.

# Infinite Lists?






- Finding the length of the list requires counting the elements.
- Be ready to interrupt.

- Grab first three elements of list
- Doesn't matter if infinite, we're only evaluating first three items

# Infinite Lists?

We're allowed to perform operations on a *finite subset* of an infinite list.

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```
*Test> x = [1..]
*Test> length x
Interrupted.
*Test> take 3 x
[1,2,3]
*Test> take 3 (drop 5 x)
[6,7,8]
*Test>
```

WinGHCi

File Edit Actions Tools Help

```
*Test> x = [1..]
*Test> zip "Hello" x
[('H',1),('e',2),('l',3),('l',4),('o',5)]
*Test>
```



- **`zip`** "zips" two lists together into tuples.
- If one list is finite, the other can be infinite.

# Types in Haskell

**Statically Typed:**

- Haskell uses static type checking.
- Every expression is assigned a type.
- If a function's arguments aren't the expected type, a compile error occurs.



**Type Inference**

- Like Python, and unlike Java, we need not specify type.
- It is inferred by the context: X = "Hello", X is a string.
- However, we can explicitly specify types.
- Good practice when we know what types we want; compiler will give errors upon type mismatch.

# Types in Haskell

`:t` can be used to reveal type:

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```
Prelude> :t 1
1 :: Num p => p
Prelude> :t 1.0
1.0 :: Fractional p => p
Prelude> :t 'a'
'a' :: Char
Prelude> :t "Hello"
"Hello" :: [Char]
Prelude> :t 1 > 2
1 > 2 :: Bool
Prelude>
```

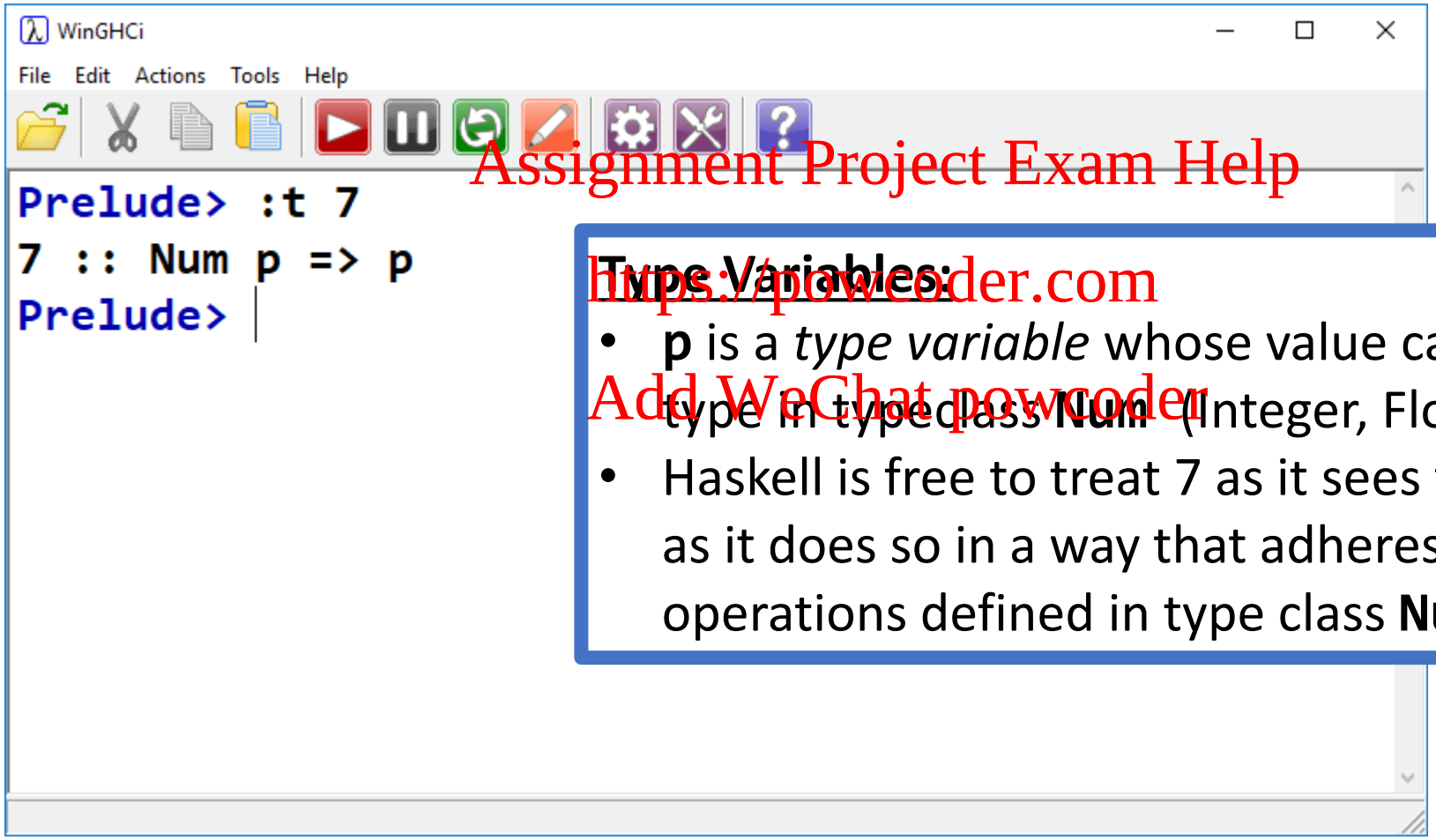


- 1 is instance of **Num** type class.
- 1.0 is instance of **Fractional** type class.



- ‘a’ is a **Char**
- “Hello” is a **[Char]**
- **[Char]** = **String**
- t is a **Bool**

# Num p => p ?





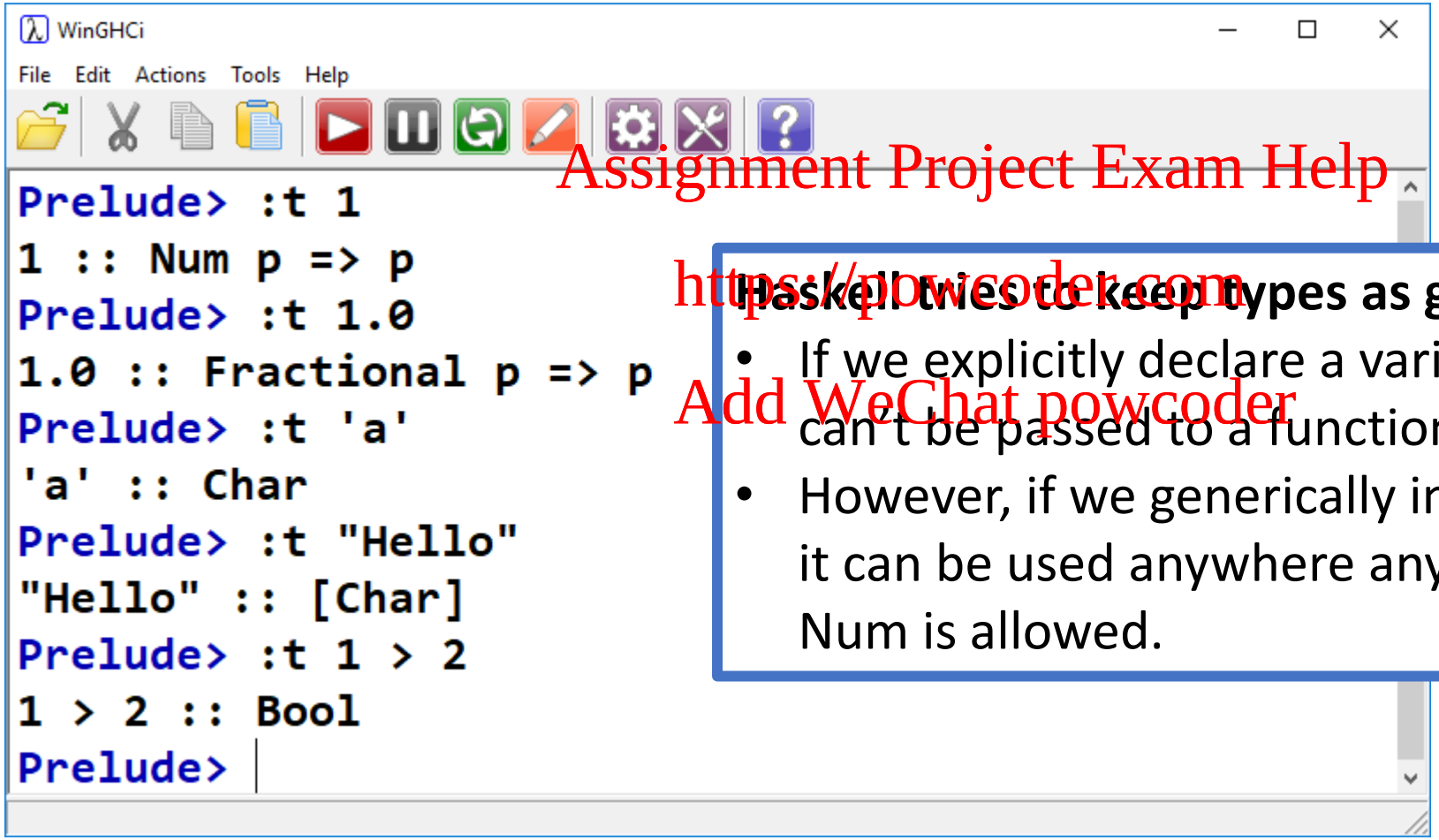





**Type Variables:**

- **p** is a *type variable* whose value can be any type in typeclass **Num** (Integer, Float, etc.)
- Haskell is free to treat 7 as it sees fit, so long as it does so in a way that adheres to the operations defined in type class **Num.**

# Typeclasses?






**Haskell tries to keep types as generic as possible**

- If we explicitly declare a variable as integer, it can't be passed to a function requiring float.
- However, if we generically infer it to be a **Num**, it can be used anywhere any other member of Num is allowed.

# Types in Haskell

We can explicitly indicate types:

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```
Prelude> :t 1
1 :: Num p => p
Prelude> :t 1.0
1.0 :: Fractional p => p
Prelude> :t 5::Int
5::Int :: Int
Prelude> :t 5.0::Double
5.0::Double :: Double
Prelude>
```



- Use **::** to assign a type
- My advice for you is to start by letting the inference engine figure it out.
- **At this point, it knows better than you.**

# Types in Haskell

We can explicitly indicate types:

WinGHCi

File Edit Actions Tools Help

```
Prelude> 5::Int
5
Prelude> 5::Double
5.0
Prelude> m = 5
Prelude> :t m
m :: Num p => p
Prelude> m = 5::Double
Prelude> :t m
m :: Double
Prelude>
```

When defining a name, can indicate type explicitly:

# Type Classes

Type polymorphism and type variables:



**Recall: Overloading**

- In languages like C++, the **==** operator is overloaded to work with many different types.



- Numeric type equality and string equality are performed differently.



- In general, if we want to compare two values of type α, we use an ***α-compare***
- α is a *type variable*, because its value is a type.

# Type Classes

Consider the equality (==) operator:

Takes two parameters, each of the same type (call it a), and returns a Boolean





This operator may not be defined for *all* types, just some.



Thus, we can associate == with a specific ***type class*** containing those types for which == is defined.

This type class is called **Eq** in Haskell.

# Eq Type Class

(==) is defined for types in typeclass **Eq**

```
(==) :: Eq a => a -> a -> Bool
```

- (==) takes two args of type **a**, where **a** is a member of type class **Eq**
- It returns **Bool**

- If a concrete type, **a**, belongs to a certain type class, we say **a** is an *instance* of that type class.
- **Int** is an instance of **Eq**, for example.

WinGHCi

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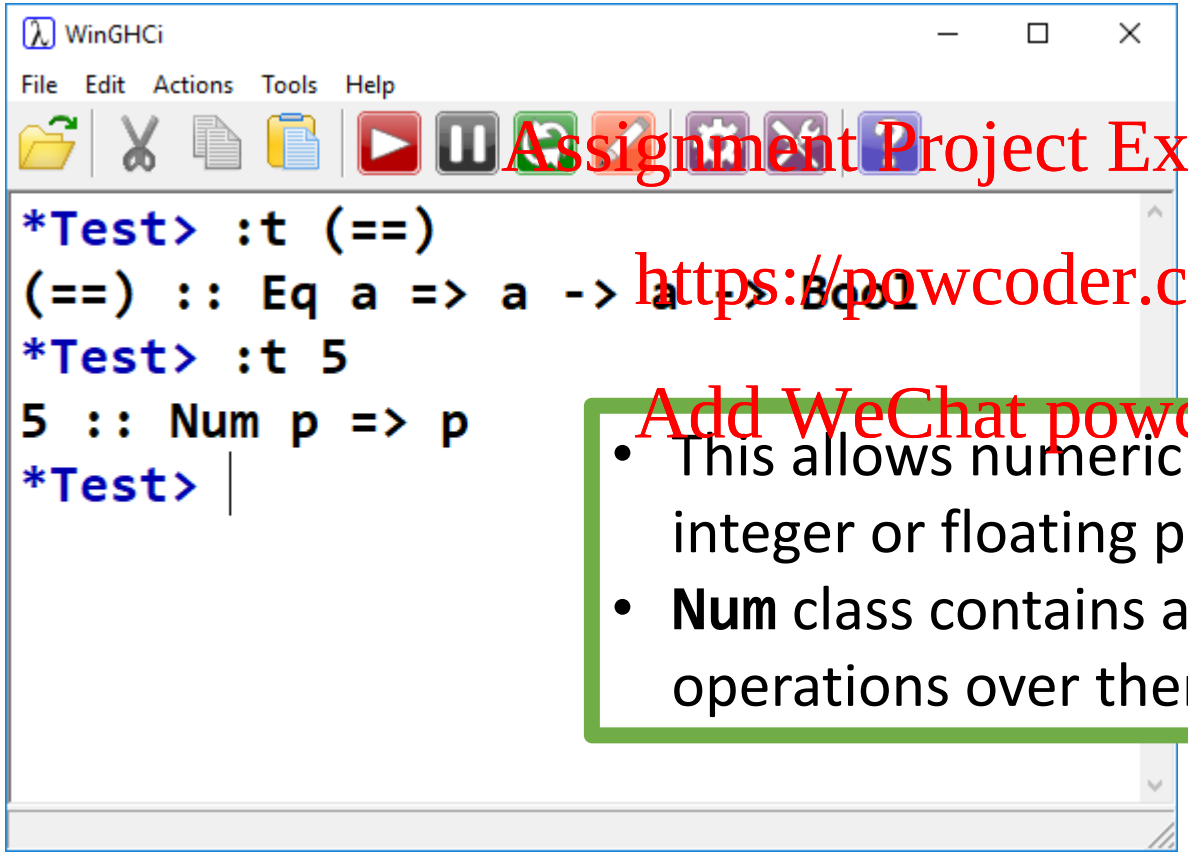
```
Prelude> :i Eq
class Eq a where
  (==) :: a -> a -> Bool
  (/=) :: a -> a -> Bool
  {-# MINIMAL (==) | (/=) #-}
   -- Defined in ‘GHC.Classes’
instance Eq a => Eq [a] -- Defined in ‘GHC.Classes’
instance Eq Word -- Defined in ‘GHC.Classes’
instance Eq Ordering -- Defined in ‘GHC.Classes’
instance Eq Int -- Defined in ‘GHC.Classes’
instance Eq Float -- Defined in ‘GHC.Classes’
instance Eq Double -- Defined in ‘GHC.Classes’
instance Eq Char -- Defined in ‘GHC.Classes’
instance Eq Bool -- Defined in ‘GHC.Classes’
```

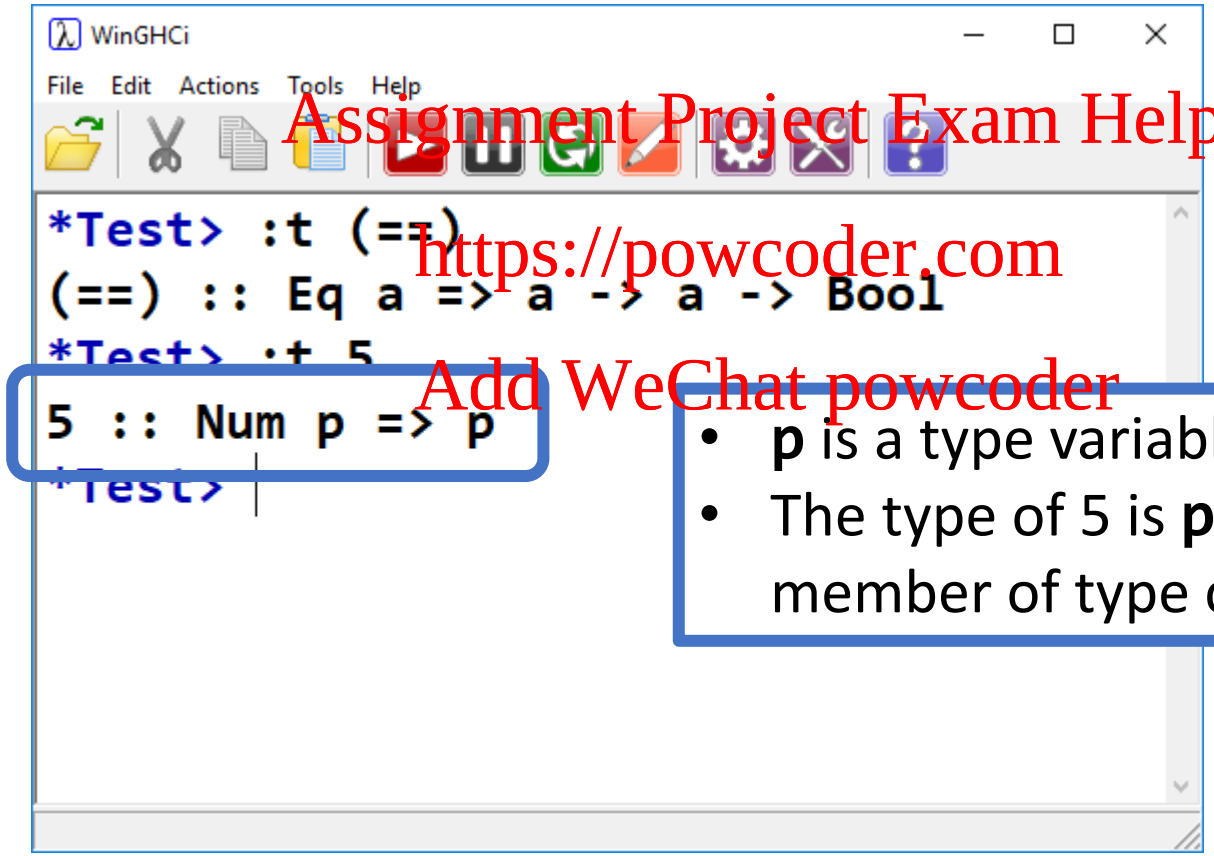
# Num Type Class






- This allows numeric values freedom to be an integer or floating point as the compiler sees fit.
- **Num** class contains all numbers, and certain operations over them such as addition.

# Num Type Class






- **p** is a type variable
- The type of 5 is **p**, and **p** is a member of type class **Num**

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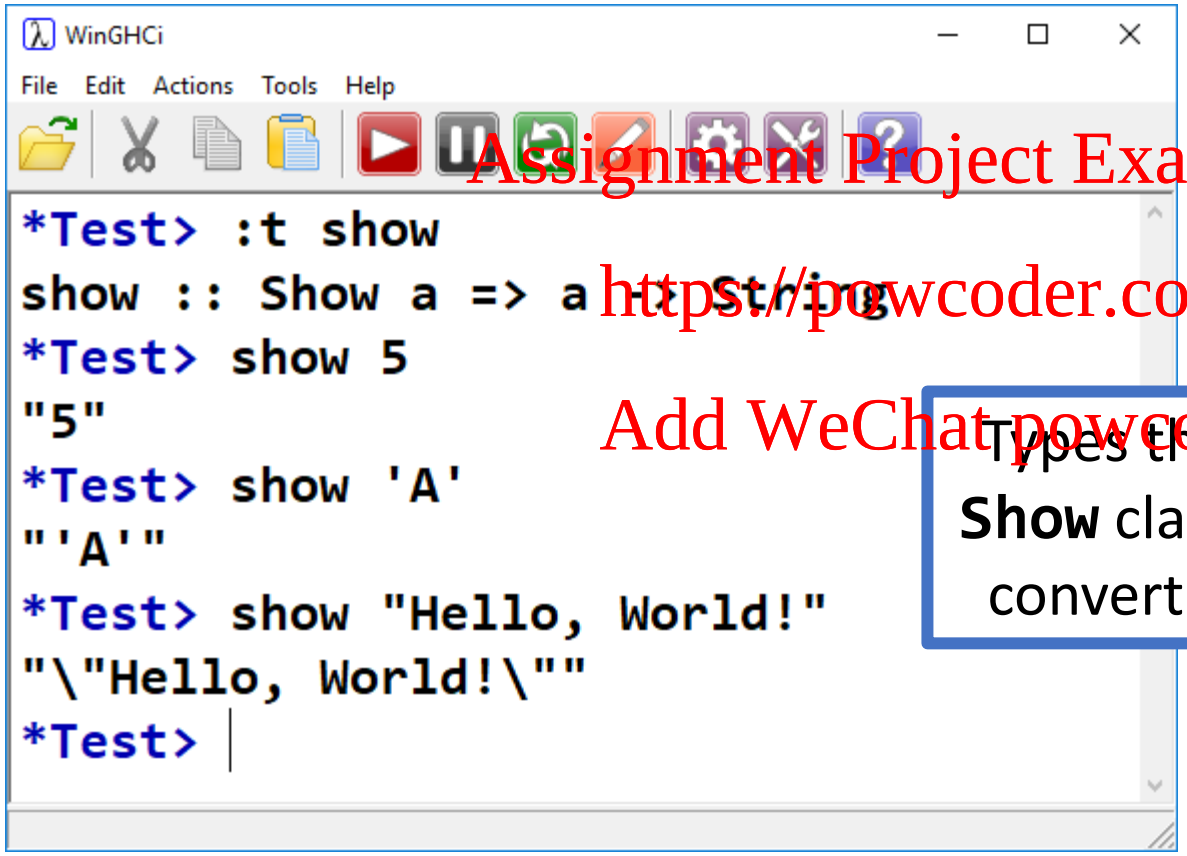
```
Prelude> :i Num
class Num a where
  (+) :: a -> a -> a
  (-) :: a -> a -> a
  (*) :: a -> a -> a
  negate :: a -> a
  abs :: a -> a
  signum :: a -> a
  fromInteger :: Integer -> a
  {-# MINIMAL (+), (*), abs, signum, fromInteger, (negate | (-)
) #-}
   -- Defined in ‘GHC.Num’
instance Num Word -- Defined in ‘GHC.Num’
instance Num Integer -- Defined in ‘GHC.Num’
```

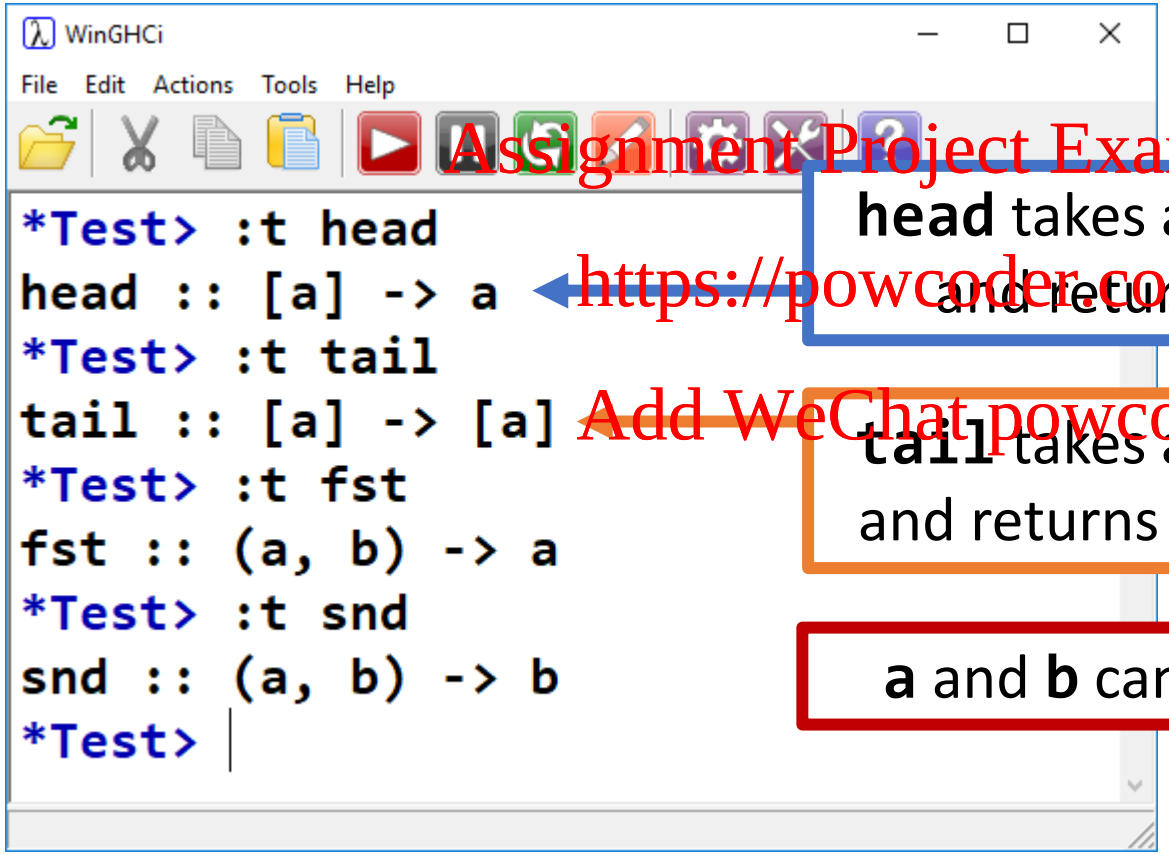
# Show Type Class






Types that are members of the **Show** class have functions which convert their value to a String.

# Function Types



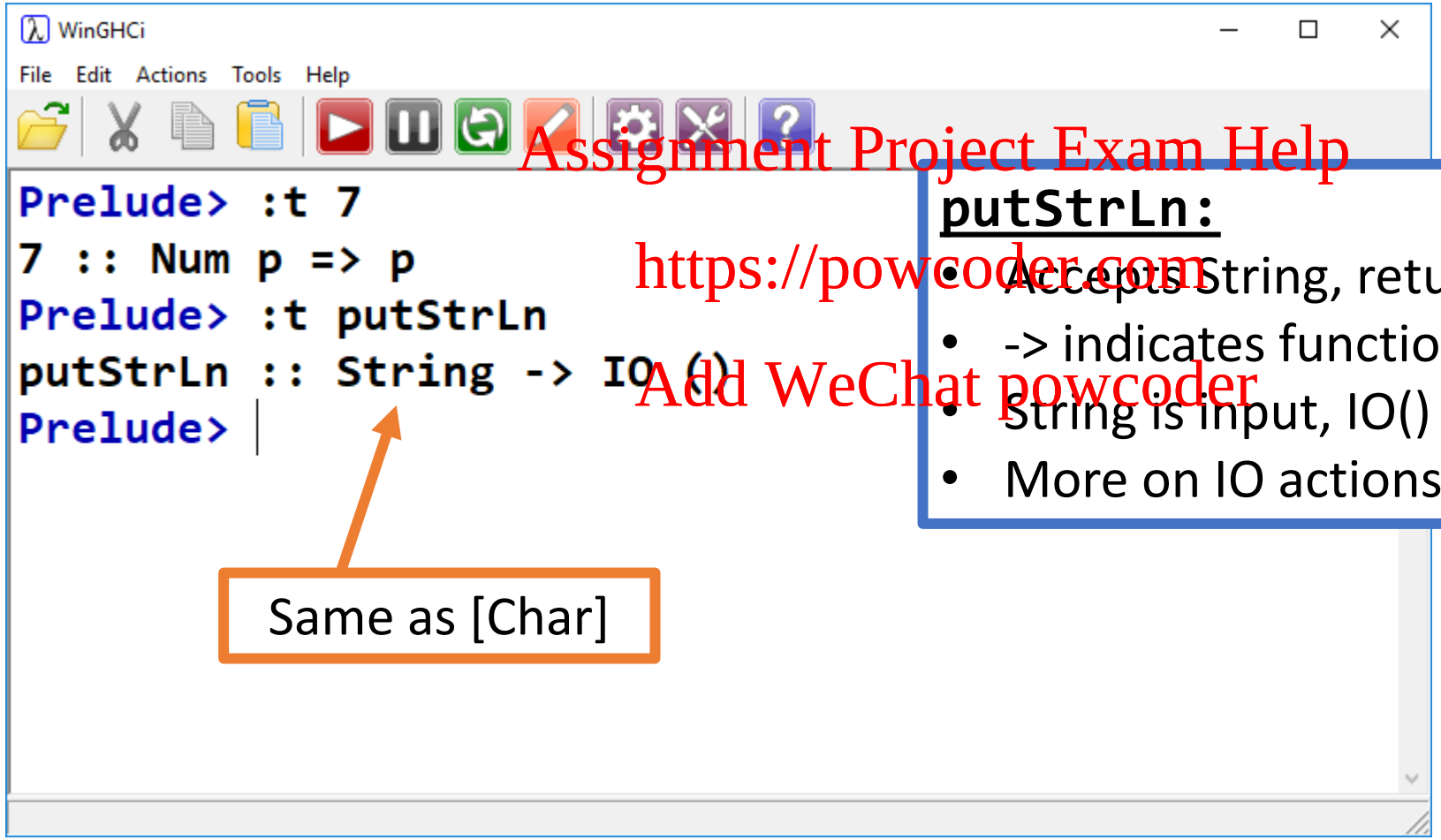



**head** takes a list containing type **a**, and returns a value of type **a**

**tail** takes a list containing type **a**, and returns a list containing type **a**

**a** and **b** can be *literally any type!*

# Function Types

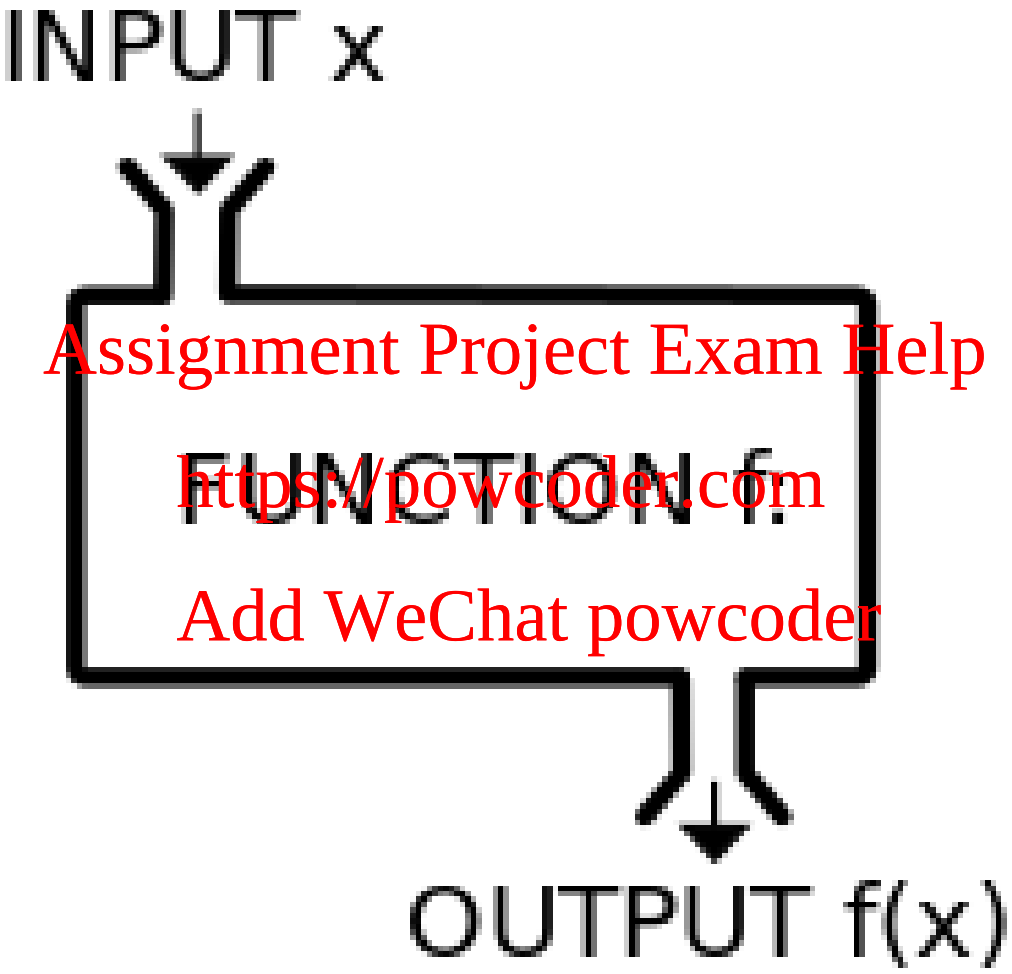





**`putStrLn:`**

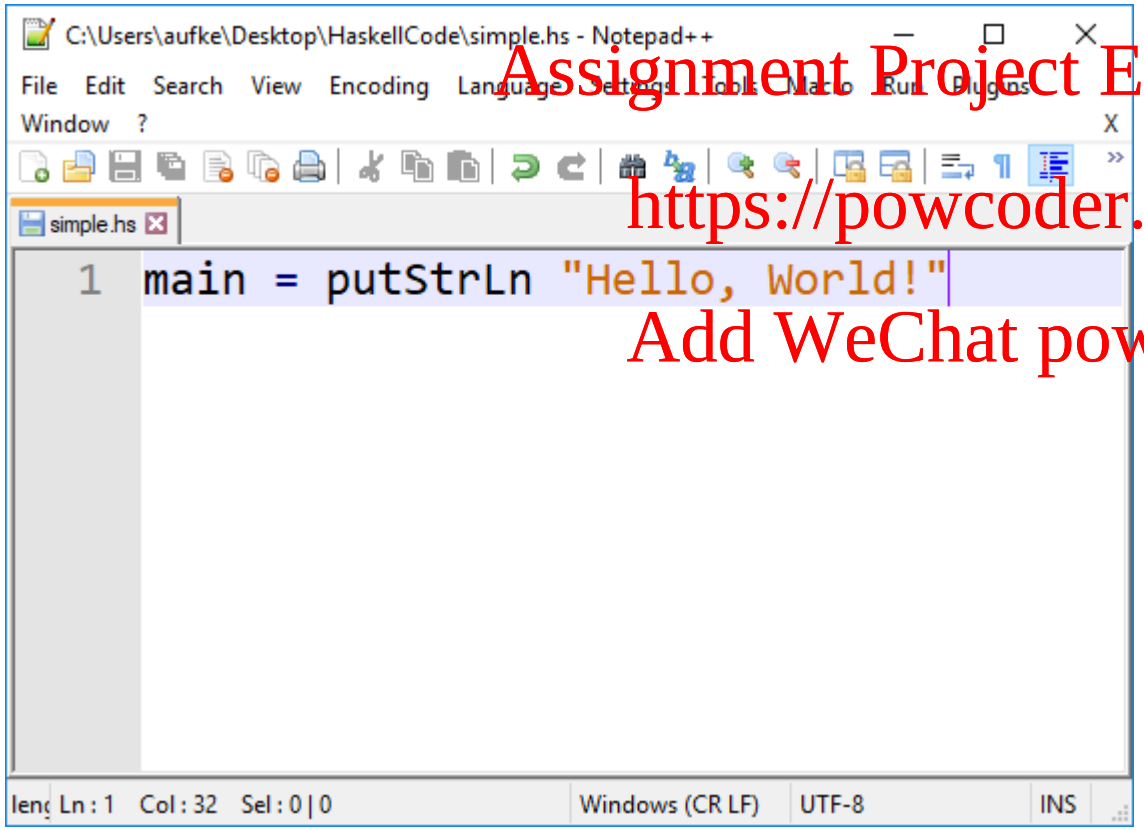
- Accepts String, returns ***IO action***.
- -> indicates function
- String is input, IO() is output.
- More on IO actions later.

We'll create our own types soon, and see how to add them to existing type classes.



# Functions in Haskell

As expected of a pure functional language, functions are central in Haskell

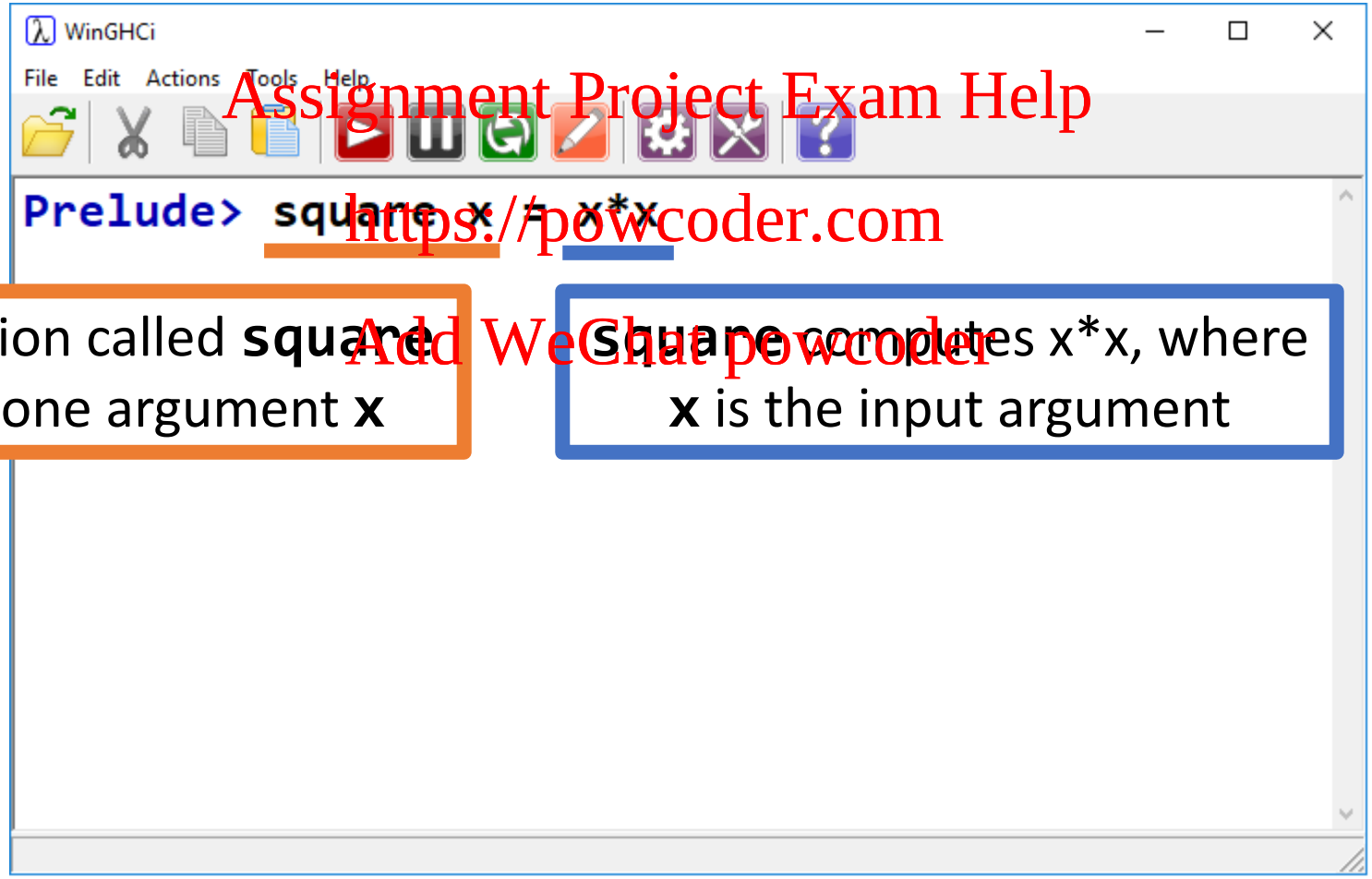





- If we're compiling our code into an executable, we need a main.
- If we're using the GHCi shell, we don't.

# Functions in Haskell

Let's start simple:



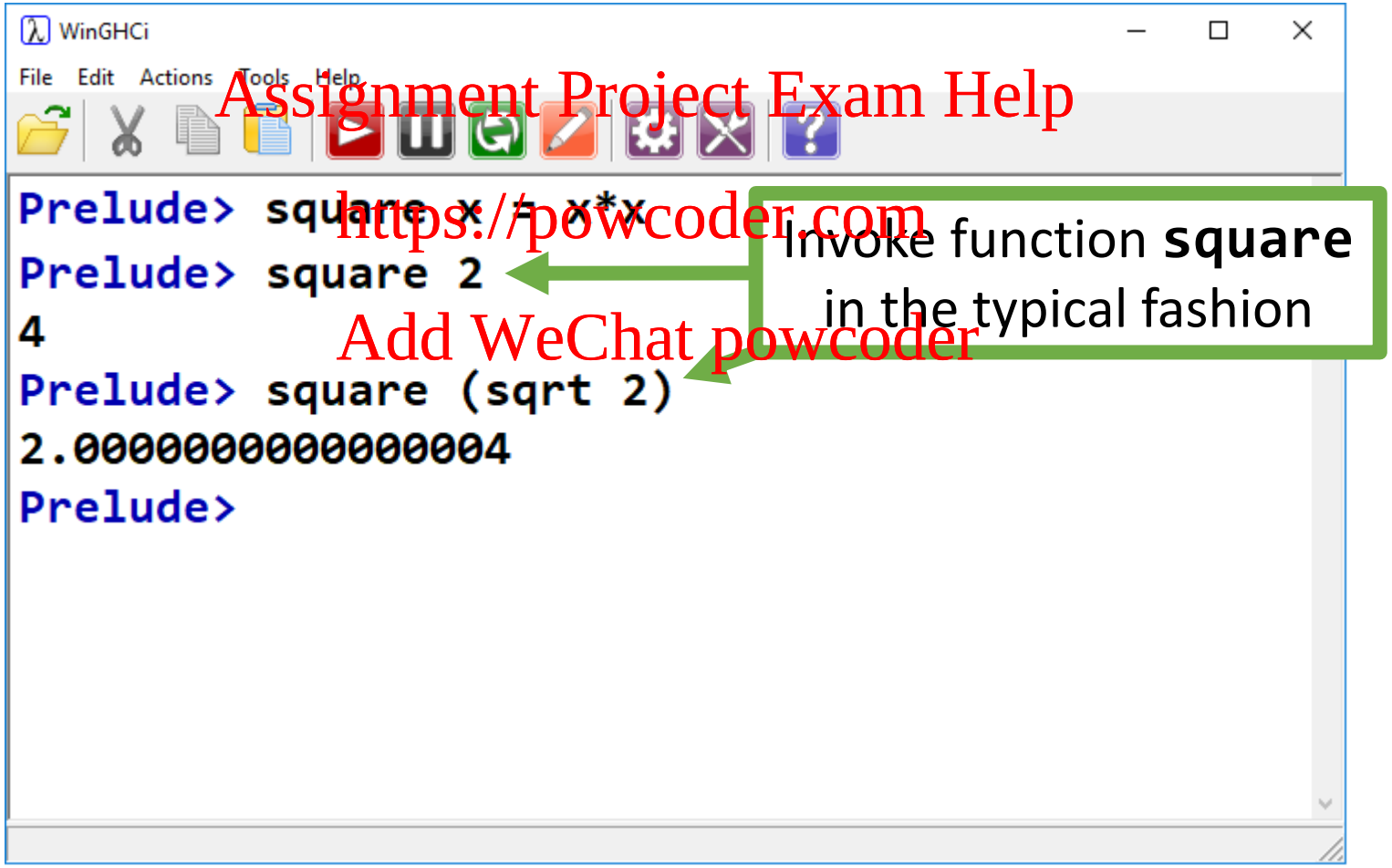



Define function called **square** that takes one argument **x**

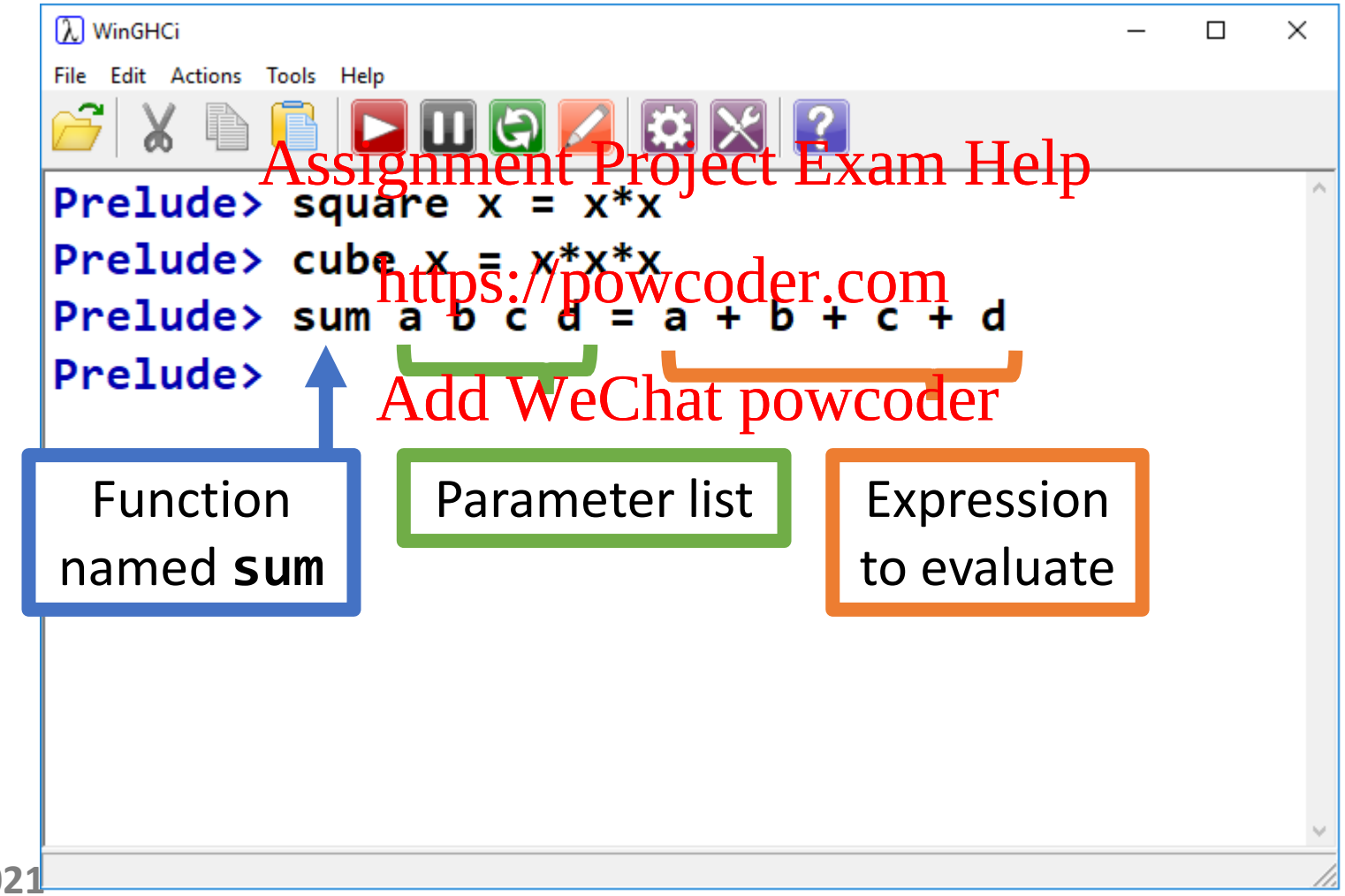
**square** computes x*x, where **x** is the input argument

# Functions in Haskell

Let's start simple:



# Functions in Haskell



# Functions in Haskell

WinGHCi

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```
Prelude> square x = x*x
Prelude> cube x = x*x*x
Prelude> sum a b c d = a + b + c + d
Prelude> sum (square 2) (cube 2) 3 4
19
Prelude>
```

Passing in four args

# Functions in Haskell

WinGHCi

File Edit Actions Tools Help

```
GHCi, version 8.4.2: http://www.haskell.org/ghc/  :? for help
Prelude> square x = x*x
Prelude> sum a b c = a+b+c
Prelude> :t square
square :: Num a => a -> a
Prelude> :t sum
sum :: Num a => a -> a -> a -> a
Prelude>
```



- Based on what we're doing in **`square`** and **`sum`** (multiplying and adding)…
- Haskell determined that input and output type should be instances of typeclass **`Num`**.
- **`(+)`** and **`(*)`** are both defined for all types in typeclass **`Num`**.

# Haskell Modules

This is getting tedious to type interactively.

C:\HaskellCode\Test.hs - Notepad++

File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ?

Test.hs HaskellList.hs

```haskell
module Test where

 square x = x*x
 cube x = x*x*x
 sum x y = x + y
```

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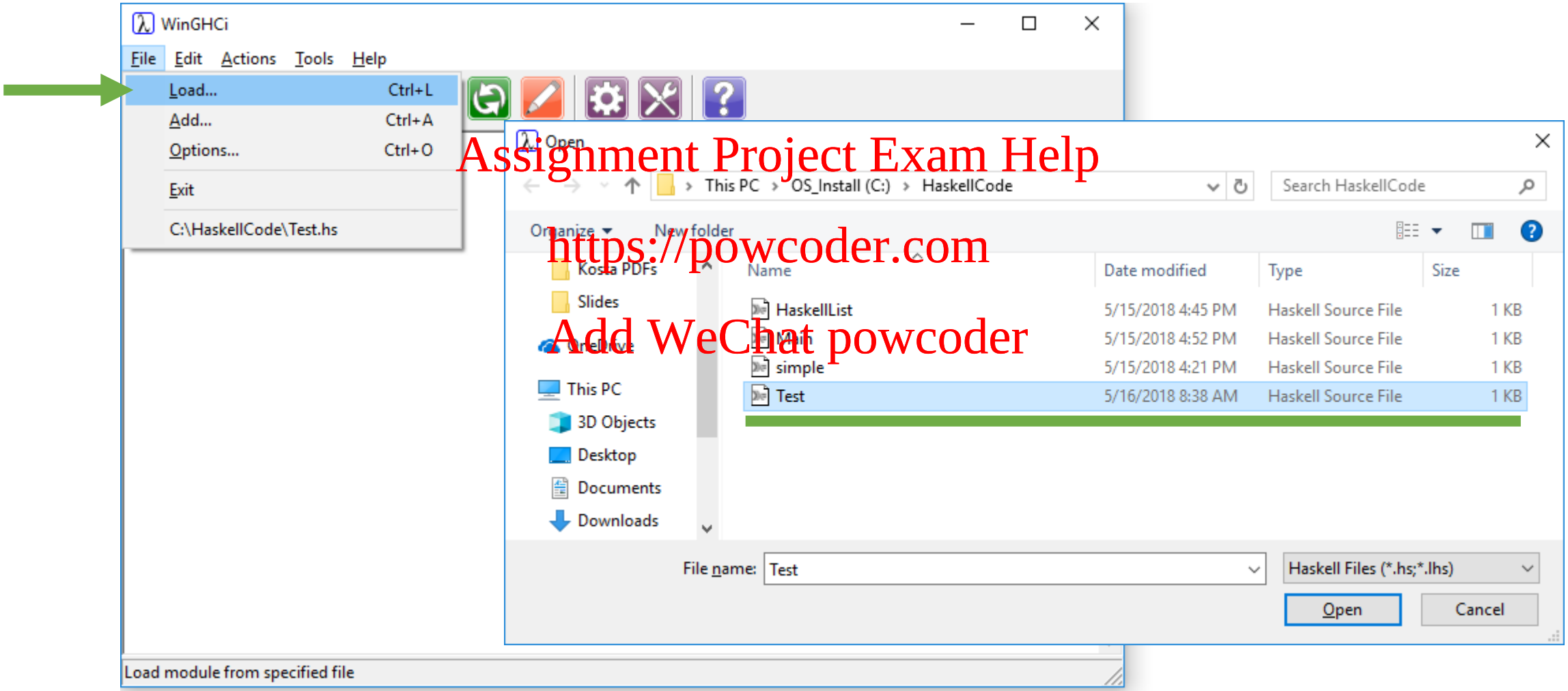
**Let's create a module!**

- Similar to modules in Elixir
- We can load the module in GHCi
- Access its functions and expressions

# Loading a Module



WinGHCi

File Edit Actions Tools Help

```
Prelude> :cd C:\HaskellCode
Prelude> :load "Test.hs"
[1 of 1] Compiling Test             ( Test.hs,
 interpreted )
Ok, one module loaded.
*Test>
```



C:\HaskellCode\Test.hs - Notepad++

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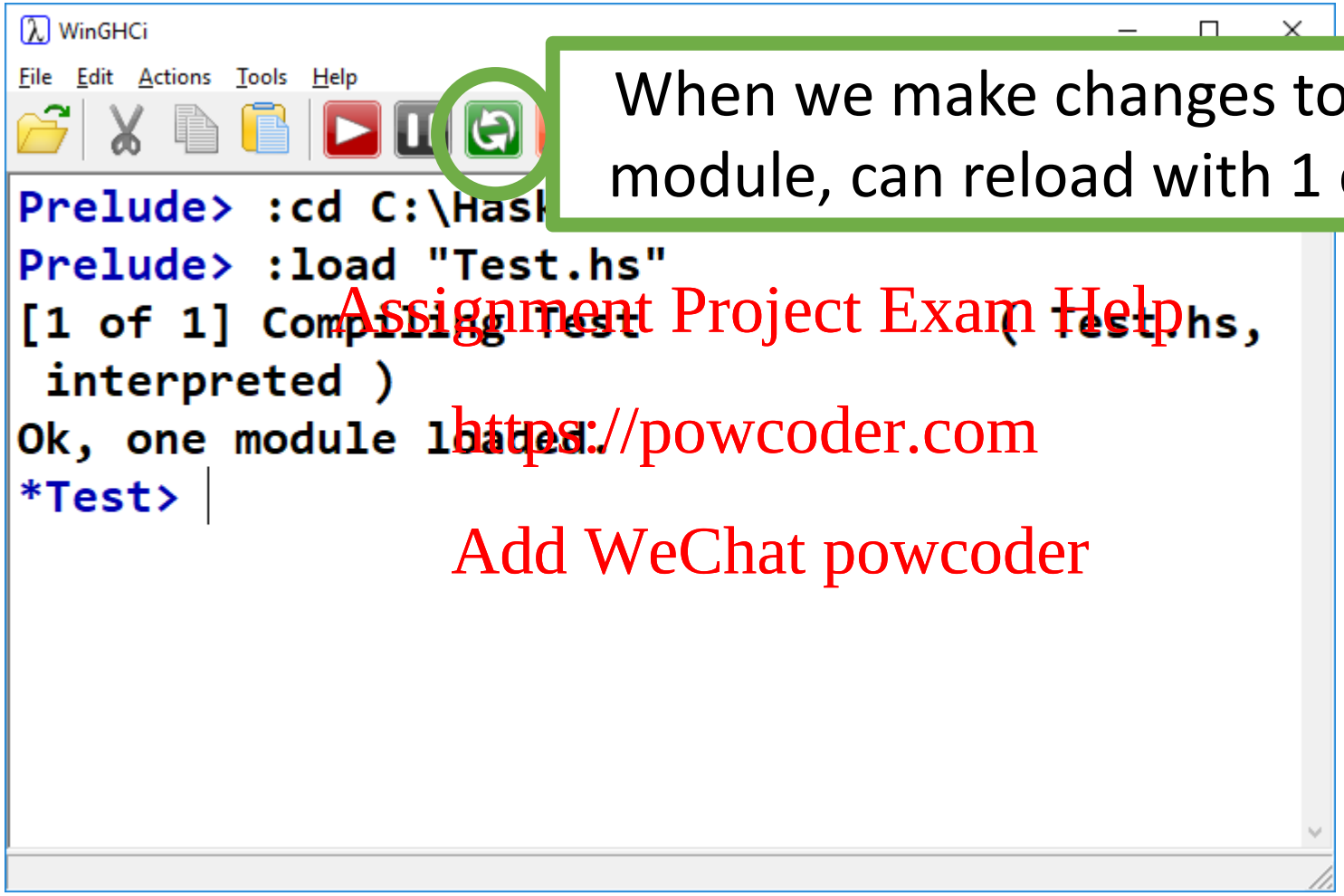
```
module Test where

square x = x*x
cube x = x*x*x
sum x y = x + y
```




When we make changes to Test module, can reload with 1 click!

# Loading a Module

Use **`:load`** in terminal GHCi:

```
Windows PowerShell
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Try the new cross-platform PowerShell https://aka.ms/pscore6

PS C:\Users\aufke\Google Drive\Teaching\CCPS 506\Resources\Code\Haskell> ghci
GHCi, version 8.10.1: https://www.haskell.org/ghc/  :? for help
Prelude> :load Test.hs
[1 of 1] Compiling Test             ( Test.hs, interpreted )
Ok, one module loaded.
*Test> cube 5
125
*Test> square 10
100
*Test> :t square
square :: Num a => a -> a
*Test>
```



Use **`:reload`** for previously loaded module

# Control Structures

## `if then else`

WinGHCi

File Edit Actions Tools Help



```
Prelude> f x = if x < 0 then 0 else 1
Prelude> f 67
1
Prelude> f 0
1
Prelude> f (-6)
0
Prelude> f -6

<interactive>:203:1: error:
    • Non type-variable argument in the constr
aint: Num (a -> p)
```



- Brackets required around negative arguments
- Otherwise it thinks you're subtracting 6 from f

# Control Structures

## `if then else if then else`

C:\HaskellCode\Test.hs - Notepad++

File Edit Search View Encoding Language Settings Tools Macro Run

Test.hs | HaskellList.hs

```haskell
module Test where

 sign x =
  if x < 0 then -1
  else if x > 0 then 1
  else 0
```

Ln : 8 Col : 2 Sel : 0 | 0 Windows (CR LF) UTF-8 INS

- Here we have a function named **`sign`**, that takes one argument x
- **It returns:**
  - -1 if x is negative
  - 1 if x is positive
  - 0 if x is 0

- If/else construct in Haskell is similar to most other languages.
- It must include a **then** and an **else**

# Control Structures

**`if then else if then else`**

C:\HaskellCode\Test.hs - Notepad++

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Test.hs | HaskellList.hs

```haskell
module Test where

 square x = x*x
 cube x = x*x*x
 sum x y = x + y

 sign x =
  if x < 0 then -1
  else if x > 0 then 1
  else 0
```

Ln : 13 Col : 2 Sel : 0 | 0 Windows (CR LF) UTF-8 INS

We can now format across multiple lines.
**HOWEVER:** Indentation matters in Haskell!

C:\HaskellCode\Test.hs - Notepad++

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Test.hs | HaskellList.hs

```haskell
module Test where

 sign x =
 if x < 0 then -1
 else if x > 0 then 1
 else 0
```

length : 92 lines : 9 Ln : 6 Col : 2 Sel : 0 | 0

WinGHCi

File Edit Actions Tools Help

```
Prelude> :reload

Test.hs:4:2: error:
    parse error (possibly incorrect indentatio
n or mismatched brackets)
  |
4 |  if x < 0 then -1   |  ^
[1 of 1] Compiling Test             ( Test.hs,
 interpreted )
Failed, no modules loaded.
Prelude>
```

C:\HaskellCode\Test.hs - Notepad++

File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ?

Test.hs | HaskellList.hs

```haskell
module Test where

 sign x =
  if x < 0 then -1
  else if x > 0 then 1
  else 0
```

length : 95 lines : 9 Ln : 4 Col : 3 Sel : 0 | 0

WinGHCi

File Edit Actions Tools Help

```
n or mismatched brackets)
  |
4 |  if x < 0 then -1    |  ^
[1 of 1] Compiling Test              ( Test.hs,
 interpreted )
Failed, no modules loaded.
Prelude> :reload
[1 of 1] Compiling Test              ( Test.hs,
 interpreted )
Ok, one module loaded.
*Test>
```

# Indenting in Haskell

C:\HaskellCode\Test.hs - Notepad++

```
1  module Test where
2
3  sign x =
4   if x < 0 then -1
5   else if x > 0 then 1
6   else 0
7
8
9
```



**Golden Rule:**
Code which is part of some expression should be indented further than the beginning of that expression

**https://en.wikibooks.org/wiki/Haskell/Indentation**

If all that weren't enough, Tabs don't work properly unless they're 8 spaces exactly.

# Haskell Tutorials/References:



https://en.wikibooks.org/wiki/Yet_Another_Haskell_Tutorial





http://cheatsheet.codeslower.com/CheatSheet.pdf