Introduction to Functional Programming and Haskell

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Program Design and Data Structures

Based on notes by Tjark Weber, Lars-Henrik Eriksson, Pierre Flener, Sven-Olof Nyström

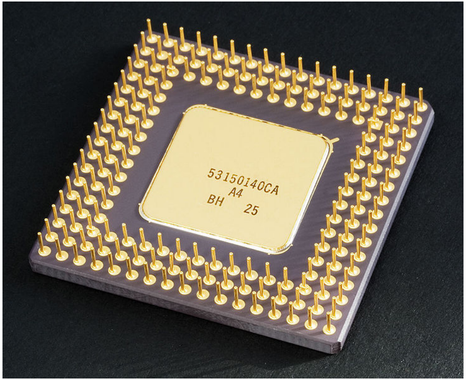
Today

- Introduction to functional programming
- Introduction to Haskell

Introduction to Functional Programming

Abstraction from Hardware

Allmost all computer hardware is imperative (i.e., executes a sequence of instructions that change the state of the machine).



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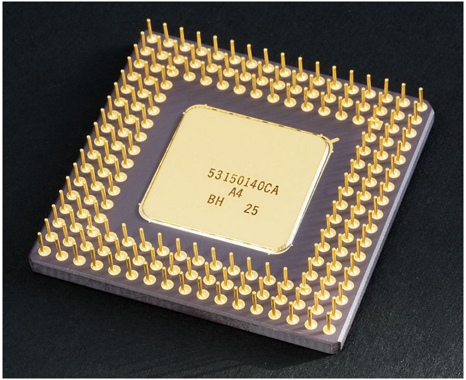

However, high-level programming languages provide a **higher level of abstraction**.

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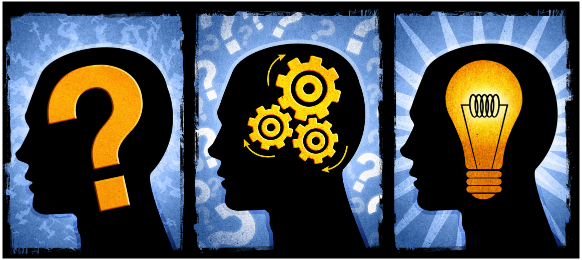

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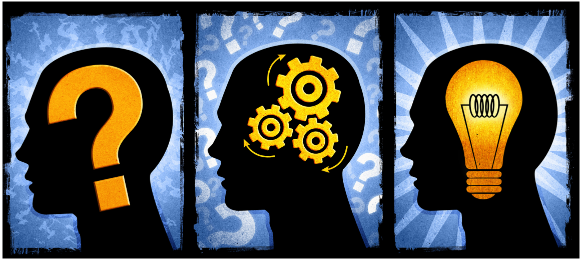

Programmers use many different high-level programming languages: e.g., C, C++, Java, PHP, Perl, Python, MATLAB, Lisp, Haskell.

Programming Paradigms

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imperative
(e.g., C)

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In practice many “problems” are engineering challenges (rather than mathematical functions), and these can be much **easier** to solve in one language or another.

Programming without mutable variables, loops or shared state.

Think different.

Why Functional Programming?

- Shorter, more readable code

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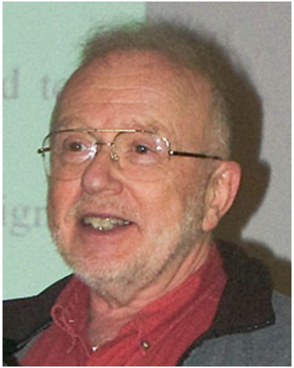

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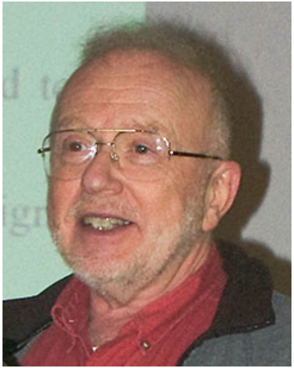
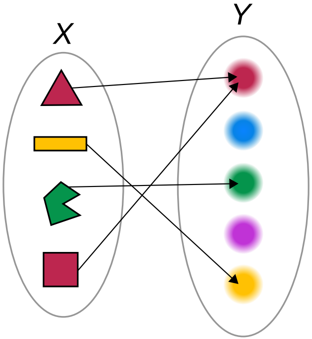


David Parnas (born 1941) is a Canadian early pioneer of software engineering. He developed the concept of information hiding in modular programming.

http://en.wikipedia.org/wiki/David_Parnas

Functions



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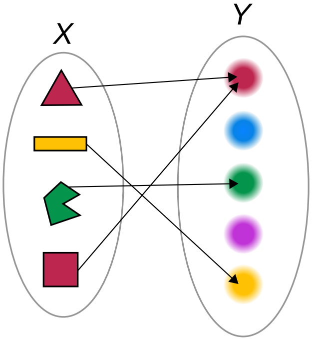

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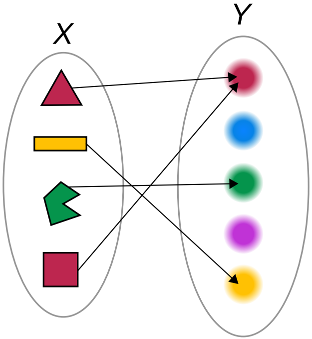

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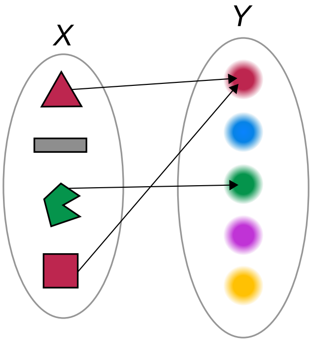
We write $f : X \to Y$ for a function f from X to Y.

Partial Functions



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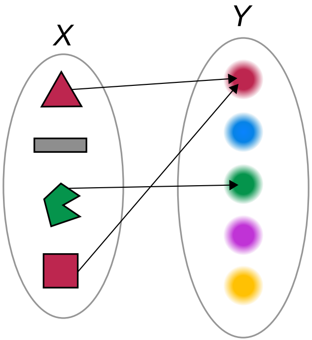

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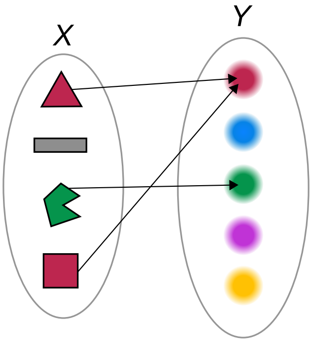

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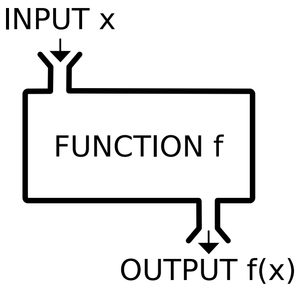

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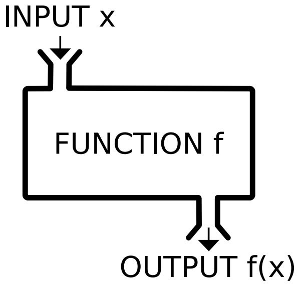

A function may be given by an **expression** that determines the output value. For example,

```
double n = 2 * n
```

Function Composition

Function composition is the application of one function to the results of another, to produce a new function.

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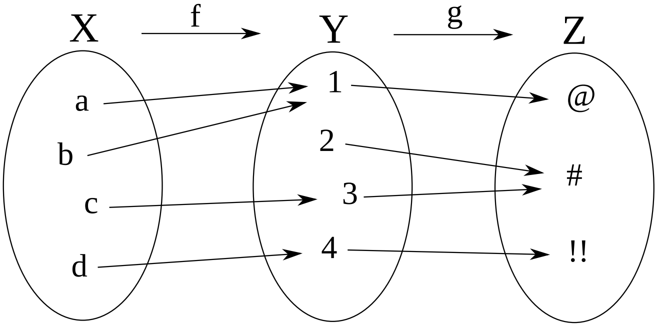

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- Recursion

Introduction to Haskell

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Some aspects of the language are slightly intricate. We'll try to introduce these gently, but they may surprise you from time to time.

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(If you install from some other source, make sure that you get "Haskell Platform", and not one of the cut-down distributions.)

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`Prelude>` is the GHCi prompt. You can now enter Haskell expressions, and GHCi will evaluate them for you!

Haskell Expressions: Arithmetic

```
2 + 15

49 * 100

1892 - 1472

5 / 2

50 * 100 - 4999

(50 * 100) - 4999

50 * (100 - 4999)

5 * (-3)
```

Haskell Expressions: Boolean Algebra

```haskell
True && False

True && True

False || True

not False

not (True && True)
```

GHCi: Interrupting and Leaving

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```
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To leave GHCi, type **:quit** at its prompt:

```
Prelude> :quit
Leaving GHCi.
```

Alternatively, press **Ctrl+D**.

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In fact, Haskell—like other modern languages—is Turing-complete. Any (mathematical) problem that can be solved by a computer program at all, can be solved by a Haskell program.

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(These are just examples. You can't really tell valid from invalid programs yet, because we haven't discussed the syntax of Haskell. We will introduce it bit by bit in the course, mostly through examples of valid programs.)

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However, GHC can't know what you had in mind ...

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- `+` means addition
- `2+15` means "the sum of 2 and 15", i.e., 17
- `f x` means "the function `f` applied to the argument `x`"

Syntax and Semantics: Common Descriptions

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It is possible—but a lot of work—to define the semantics of every program construct equally precisely. In practice, programmers mostly rely on informal descriptions (e.g., in English).

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⟶     11    < 5 * 2
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⟶       False
```

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```
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--> 3 +   8  < 5 * 2
-->     11    < 5 * 2
-->     11    <  10
-->       False
```

To evaluate functions applied to arguments, Haskell uses an evaluation strategy known as **non-strict evaluation**. Arguments are evaluated only if their value is needed in the evaluation of the function body. More on this later.

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2*3 + 4*5 ⟶ 6 + 4*5 ⟶ 6 + 20 ⟶ 26
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An expression is called **pure** if it has no side effects (such as I/O).

For pure expressions, the order of evaluation does not matter—the result is always the same.

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Therefore, functional programming is well-suited for parallel computing (e.g., multi-core machines).

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Later, we will see programs where spaces do matter.

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These comments may extend over several lines when used in Haskell programs.

Runtime Errors (aka Exceptions)

Not every expression can be evaluated to a (sensible) value: e.g.,

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Prelude> div 1 0
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Later, we'll see how to recover from an exception, and how you can write your own functions that throw exceptions.

Types

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At the hardware level, data is (mostly) just bits and bytes. Consequently, machine code is (mostly) untyped. However, many high-level languages offer data types.

Basic Types in Haskell

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Note that `1`, `1.0`, `'1'` and `"1"` are all different.

Seeing Types in GHCi

You can use `:type expr` to have GHCi show the type of `expr`.

```
Prelude> :t 'a'
'a' :: Char
Prelude> :t not True
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You can also `:set +t` to see the type of all expressions that you enter.

```
Prelude> :set +t
Prelude> 'a'
'a'
it :: Char
Prelude> not True
False
it :: Bool
```

Function Types

Also functions have types. For instance,

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Prelude> :t not
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Here, the first `Bool` is called the **argument type** and the second `Bool` is called the **result type** of the function.

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Here, the first `Bool` is called the **argument type** and the second `Bool` is called the **result type** of the function.

-> is a **type constructor**: when applied to two existing types, it constructs a new type (namely, a function type).

Expression Language, Type Language

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When we write a program, it is clear from the context whether we are writing an expression or a type. For instance,

```
expr :: Type
```

Type Checking

What should `32 + "1"` mean?

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In a **weakly typed** language, the result depends (on the language). It could be `33`, or `"321"`, or . . .

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In a language with **static** type checking, the compiler inspects the program and generates an error. Translation to machine code fails.

In a language with **dynamic** type checking, the compiler translates the program to machine code that performs type checking at run time, i.e., that generates an error when it is executed.

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Every expression has a type.

Type Inference

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In Haskell, this is (mostly) not necessary. Instead, the types of expressions are automatically **inferred** by (a type inference algorithm that is part of) the Haskell implementation.

This happens statically, i.e., without running the program.

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Again, **try to understand** these error messages! And be patient with GHC: it can't know what you really had in mind ...