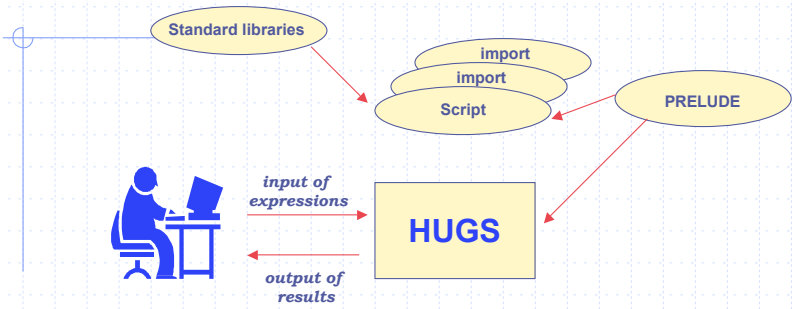
Algorithmic Imperative Languages

- variables
- assignment
- if condition then action1 else action2
- loop
  - while condition do action
  - repeat action until condition
  - for i = start to finish do action
- block
  - begin program end
- data types (extendible)
- record
- data structures (for algorithms)
  - predefined | user defined
  - ordered sets od data
- abstract data types
  - data structure + basic operations
  - forming a conceptual machine
- procedures
  - extend the language expressive power
  - increase transparency of the program
- recursion

Functional Programming Languages

- declarativeness
  - encoding rules of tranformation
  - rather than prescribing execution
- every object
  - is a function - which itself can be an object
- application as the main operation
- evaluation (β-reduction)
- referential transparency -
  - replace names by their values at any
  - time (substituting equals by equals)
- higher order functions
  - function(function) $\rightarrow$ function
- polymorphism
  - same algorithm works on many kinds of inputs
- recursion



a program in Haskell (script) is a list of function definitions
it is recorded in a file loaded into the system by :load

the programme can be changed and reloaded by :reload

programs may import other programs


```
__   __ __  __  ____   ___     ____________________________________
||   || ||  || ||  || ||__      Hugs 98: Based on the Haskell 98 standard
||___|| ||__|| ||__||  __||     Copyright (c) 1994-2001
||---||         ___||           World Wide Web: http://haskell.org/hugs
||   ||                        Report bugs to: hugs-bugs@haskell.org
||   || Version: December 2001 ____________________________________

Haskell 98 mode: Restart with command line option -98 to enable extensions

Reading file "Macintosh HD:Desktop Folder:LinzFPDB:hugs98:lib:Prelude.hs":

Hugs session for:
Macintosh HD:Desktop Folder:LinzFPDB:hugs98:lib:Prelude.hs
Type :? for help

Prelude>
Prelude> 1 + 2
3
Prelude> (+1) 2
3
Prelude> + 1 2
ERROR - Syntax error in expression (unexpected token)
Prelude> 5*6
30
Prelude> 5*6/2
15.0
Prelude> (((1 + 3) * 5 - 2 * 3 + 17/2) * (3 + 8) - 17/2) * 2.5
597.5
```

```
Prelude> pi
3.14159
Prelude> sin pi
-8.74228e-08
Prelude> log pi
1.14473
Prelude> sqrt 5
2.23607
Prelude> sqrt 100
10.0
Prelude> sin 0
0.0
Prelude> log (sin (pi/4))
-0.346574
```



```
Prelude> False
False
Prelude> True
True
Prelude> not False
True
Prelude> not True
False
Prelude> not (not True)
True
Prelude> not (not False)
False
Prelude> not False && True
True
Prelude> True || False
True
Prelude> not (True && False)
True
Prelude> 5 == 4
False
Prelude> 5 /= 5
False
Prelude> 5 == 5
True
```

```
Prelude> reverse "Stefan"
"nafetS"
Prelude> reverse (reverse "Stefan")
"Stefan"
Prelude> even 3
False
Prelude> even 4
True
Prelude> sum [1..10]
55
Prelude> filter even [1..10]
[2,4,6,8,10]
Prelude> odd  2
False
Prelude> odd  3
True
```



```
Prelude> filter odd [1..10]
[1,3,5,7,9]
Prelude> sum (filter even [1..10])
30
Prelude> sum (filter odd [1..10])
25
Prelude> reverse (filter odd [1..10])
[9,7,5,3,1]
Prelude> map (1+) [1..10]
[2,3,4,5,6,7,8,9,10,11]
Prelude> map (1+) (map (1+) [1..10])
[3,4,5,6,7,8,9,10,11,12]
Prelude> filter even $$
[4,6,8,10,12]
Prelude> putStr "hello"
hello
Prelude> print "hello"
"hello"
Prelude> > putStr "How " >> putStr "are " >> putStr "you"
How are you
Prelude>:q
```

```
Prelude> :?
LIST OF COMMANDS:  Any command may be abbreviated to :c
                   where c is the first character in the full name.

:load <filenames>     load modules from specified files
:load                 clear all files except prelude
:also <filenames>     read additional modules
:reload               repeat last load command
:project <filename>   use project file
:edit <filename>      edit file
:edit                 edit last module
:module <module>      set module for evaluating expressions
<expr>                evaluate expression
:type <expr>          print type of expression
:?                    display this list of commands
:set <options>        set command line options
:set                  help on command line options
:names [pat]          list names currently in scope
:info <names>         describe named objects
:browse <modules>     browse names defined in <modules>
:find <name>          edit module containing definition of name
:!command             shell escape
:cd dir               change directory
:gc                   force garbage collection
:version              print Hugs version
:quit                 exit Hugs interpreter
```


file First.hs

```
-- content of First.hs

size :: Int
size = 10 + 20

square :: Int -> Int
square n = n*n

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

example :: Int
example = double (size - square (2+2))

plus5 :: Int -> Int
plus5 a = a + 5

plus :: Int -> Int  -> Int
plus a  b = a + b

power4 :: Int -> Int
power4 n = square (square(n))

power3 n = square(n) * n

-- end of file
```

```
Prelude> :l First
Reading file "First.hs":

Hugs session for:
Macintosh HD:Desktop
Folder:LinzFPDB:hugs98:lib:Prelude.hs
First.hs
Main> size
30
Main> square 3
9
Main> double 5
10
Main> example
28
Main> plus 5 7
12
Main> plus 3 5
8
Main> power4 2
16
Main> power3 2
8
Main>
```

```
Main> power3 (plus5 example)
35937
Main> double (plus 5 4)
18
Main> (plus 5 4) * (5 - 4)
9
Main> double (square ((plus 5 4) * (5 - 4) - example))
722
Main> $$
722
Main> div 13 5
2
Main> mod 13 5
3
Main> 13 / 5
2.6
Main> :t square
square :: Int -> Int
Main>:q
```


Style

function definitions are equations and should be preceeded by type declarations (which can be omitted)

filename.hs

```
-- this is a definition of my plus

plus :: Int -> Int  -> Int
plus a  b = a + b
```

conventional style

filename.lhs

```
this is a definition of my plus

> plus :: Int -> Int  -> Int
> plus a  b = a + b
```

literate style

every value and function has a type

every script is checked before the execution, hence type errors are not possible at run time

currying

functions of multiple arguments are usually curried

```
plus        :: (Int, Int) -> Int
plus (x, y) =  x + y
```

conventional

```
plusC       :: Int -> Int -> Int
plusC x y   =  x + y
```

curried

function plusC can be applied to one argument -
(plusC 3) takes a number and adds 3 to it

left associativity

function application has the highest priority

plusC x y means (plusC x) y rather than plus (x y)

square square 3 means (square square) 3

```
Main> square square 3
ERROR - Type error in application
*** Expression     : square square 3
*** Term           : square
*** Type           : Int -> Int
*** Does not match : a -> b -> c

Main> :type square
square :: Int -> Int
```

```
Main>
Main> square (square 3)
81
Main>
```

function composition

if f: A → B and g: B → C
then (f . g) : A → C (f . g)x = f (g x)

```
Main> (square . square) 3
81
Main>
```

```
Main> square . square 3
ERROR - Type error in application
*** Expression     : square . square 3
*** Term           : square 3
*** Type           : Int
*** Does not match : a -> b
```


Boolean

Constants	True, False
Logical operators	&& || not (and or not)
Relational operators	== /= > >= < <=

== and /= are used for both **integers** and **booleans**; the operators are termed **overloaded**

```
Main> (1==2) && (1/0 > 5)
False

Main> 1/0
Program error: {primDivDouble 1.0 0.0}
Main >
```

evaluated as
(1 == 2) && whatever
False && whatever
False

lazy evaluation

```
xOR      :: Bool -> Bool -> Bool
xOR x y  = (x || y) && not (x && y)
```

```
nAND     :: Bool -> Bool -> Bool
nAND x y = not (x && y)
```

```
same3              :: Int -> Int -> Int -> Bool
same3 m n p        = (m == n) && (n == p)
```

```
same3  1  1  7
 (m == n) && (n == p)
 (1 == 1) && (1 == 7)
 True && False
 False
```

```
same4              :: Int -> Int -> Int -> Int -> Bool
same4 m n p q      = (m == n) && (n == p) && (p == q)
```

```
same4              :: Int -> Int -> Int -> Int -> Bool
same4 m n p q      = same3 m n p && (p == q)
```


guards and conditionals

```
bigger     :: Int -> Int -> Int
bigger  x y
      | x >= y          = x
      | otherwise       = y
```

```
biggest3   :: Int -> Int -> Int -> Int
biggest3  x y z
      | x >= y && x >= z          = x
      | y >= z                    = y
      | otherwise                 = z
```

```
bigif      ::  Int -> Int -> Int
bigif  x y
           = if x >y then x else y
```

ASCII codes

Char

```
Prelude> :type ord
ord :: Char -> Int

Prelude> ord 'a'
97
Prelude> ord 'b'
98
Prelude> ord 'z'
122
Prelude> ord 'A'
65
Prelude> ord 'B'
66
Prelude> ord 'Z'
90
Prelude> ord '\t'
9
Prelude> ord '\n'
10
Prelude>
```

```
Prelude> :type chr
chr :: Int -> Char

Prelude> chr  97
'a'
Prelude> chr  98
'b'
Prelude> chr  122
'z'
Prelude> chr  65
'A'
Prelude> chr  66
'B'
Prelude> chr  90
'Z'
Prelude> chr  9
'\t'
Prelude> chr  10
'\n'
Prelude>
```


Char

```
Prelude> a
ERROR - Undefined variable "a"
Prelude> 'a'
'a'
Prelude> 3
3
Prelude> 3 == 3
True

Prelude> '3' == 3
ERROR - Illegal Haskell 98 class constraint in inferred type
*** Expression : '3' == 3
*** Type       : Num Char => Bool

Prelude> 'a' == 3
ERROR - Illegal Haskell 98 class constraint in inferred type
*** Expression : 'a' == 3
*** Type       : Num Char => Bool

Prelude> 'a' == '3'
False
Prelude>
```

```
-- digit to its value; zero for non-digits

digitTOnum :: Char -> Int
digitTOnum c
        | 1 < n && n <= 9       = n
        | otherwise             = 0
            where n = ord c - ord '0'
```

```
Main> digitTOnum '2'
2
Main> digitTOnum '9'
9
Main> digitTOnum '0'
0
Main> digitTOnum 'a'
0
Main>
```



```
-- how many roots in  ax^2 + bx + c = 0

howmany :: Float -> Float -> Float -> Int
howmany a b c
        | discriminant > 0      = 2
        | discriminant  == 0    = 1
        | discriminant < 0      = 0
            where discriminant = b^2 - 4 * a * c
```

local definition

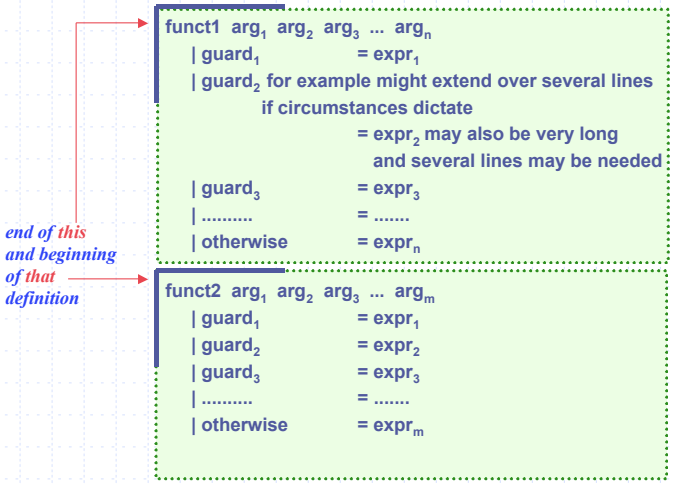
```
Main> howmany 1 (-2) 1
1
Main> howmany 5 4 3
0
Main> howmany 1 0 (-4)
2
Main>
```

x^2 -2x +1 = (x-1)^2

5x^2 + 4x 3

x^2 - 4 = (x-1)(x+1)

layout rule (blocks show the structure)



simple recursion

```
-- factorial

fac  :: Int -> Int
fac n
  | n == 0      = 1
  | n > 0       = fac (n - 1) * n
```

```
Main> fac 0
1
Main> fac 1
1
Main> fac 2
2
Main> fac 5
120
Main> fac 9
362880
Main> fac (-1)

Program error: {fac (-1)}

Main>
```

```
-- multiplication

times :: Int -> Int -> Int
times m n
      | n == 0      = 0
      | n > 0       = times m (n-1) + m


-- exponentiation

power :: Int -> Int -> Int
power  m n
       | n == 0        = 1
       | n > 0         =  times (power m (n - 1)) m
```

```
Main> power 2 4
16
Main> power 2 5
32
Main> power 2 10
1024
Main> power 3 2
9
Main> power 3 4
81
Main> power 5 4
625
Main> power 10 10
1410065408
Main> power 0 0
1
Main> power 0 1
0
Main> power 1 0
1
Main>
```



```
-- nth Fibonacci number

fib :: Int -> Int
fib n
  | n == 0    = 0
  | n == 1    = 1
  | n > 1     = fib (n - 2) + fib (n -1)
```

0	1	1	2	3	5	8	13	21
0	1	2	3	4	5	6	7	8

```
Main> fib 0
0
Main> fib 1
1
Main> fib 2
1
Main> fib 7
13
Main> fib 8
21
Main>
```

names

identifiers - alphanumeric strings, starting with a letter

functions & variables must start with a lower-case letter

types, type constructors, type classes start with a capital letter

reserved words

case	class	data	default	deriving	do
else	if	infix	infix1	infixr	instance
let	module	newtype	of	then	type
where					

tuples records (structures)

student-record

name id mark

("Hans", "s887655", 92) :: (String, String, Int)

belongs to the **tuple type**

```
type Student = (String, String, Int)
hans :: Student
hans = ("Hans", "s887655", 92)
```

```
type Cohort = [Student]
[("Hans", "s887655", 92), ("Mary", "s887123", 65), ("Anne", s8870091", 94)]
```

list of students, each elemrnt of the list is of the same type

functions over tuples - pattern matching

```
projection
first, second :: (Int, Int) -> Int
first (x, y) = x
second (x, y) = y
```

```
Prelude> fst ("john", "mary")
"john"
Prelude> snd ("john", "mary")
"mary"
Prelude> fst (18, 20)
18
Prelude> snd (18, 20)
20
```



```
type Student = (String, String, Int)
getID :: Student -> String
getID (name, id, mark) = id
```

```
Main> getID ("Mary", "s887123", 65)
"s887123"
Main>
```

```
addPair :: (Int, Int) -> Int
addPair (x, y) = x+y

min3, max3 :: Int -> Int -> Int -> Int
min3 x y z
   | x <= y && x <= z    = x
   | y <= z              = y
   | otherwise           = z

max3 x y z
   | x >= y && x >= z    = x
   | y >= z              = y
   | otherwise           = z


middle :: Int -> Int -> Int -> Int
middle x y z
   | between x y z       = x
   | between y x z       = y
   | otherwise           = z

between :: Int -> Int -> Int -> Bool
between x y z = (x >= y &&  x<=z) || (x >=z &&  x <= y)

orderTriple :: (Int, Int, Int) -> (Int, Int, Int)
orderTriple (x, y, z) = (min3 x y z, middle x y z,  max3 x y z)
```

```
Main> orderTriple (18, 12, 30)
(12,18,30)
Main> orderTriple (1,2,3)
(1,2,3)
Main> orderTriple (3,2,1)
(1,2,3)
Main> orderTriple (2,1,3)
(1,2,3)
Main> orderTriple (18, 120, 34)
(18,34,120)
```