Standard Libraries for the Programming Language

Haskell 98

\( \lambda \)

A Non-Strict, Purely Functional Language

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Standard Libraries
for the
Haskell 98
Programming Language

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Simon Peyton Jones\(^8\) [editor]
John Hughes\(^3\) [editor]
Lennart Augustsson\(^3\)
Dave Barton\(^7\)
Brian Boutel\(^4\)
Warren Burton\(^5\)
Joseph Fasel\(^6\)
Kevin Hammond\(^2\)
Ralf Hinze\(^12\)
Paul Hudak\(^1\)
Thomas Johnsson\(^3\)
Mark Jones\(^9\)
John Launchbury\(^14\)
Erik Meijer\(^10\)
John Peterson\(^1\)
Alastair Reid\(^4\)
Colin Runciman\(^13\)
Philip Wadler\(^11\)

Authors’ affiliations: (1) Yale University (2) University of St. Andrews (3) Chalmers University of Technology (4) Victoria University of Wellington (5) Simon Fraser University (6) Los Alamos National Laboratory (7) Intermetrics (8) Microsoft Research, Cambridge (9) University of Nottingham (10) Utrecht University (11) Bell Labs (12) University of Bonn (13) York University (14) Oregon Graduate Institute
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Preface

This document defines the standard libraries for Haskell 98.

The libraries presented here represent a selection of basic functionality that is expected to
be useful to many Haskell programmers. Most implementations provide further libraries
which are not a recognized part of the Haskell standard.

The latest version of this report, as well many other available libraries, can be found on the

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1 Introduction

This document defines the standard libraries for Haskell 98. Like the Prelude, these libraries are a required part of a Haskell implementation. Unlike the Prelude, however, these modules must be *explicitly* imported into scope.

When possible, library functions are described solely by executable Haskell code. Functions which require implementation-dependent primitives are represented by type signatures without definitions. Some data types are implementation-dependent: these are indicated by comments in the source.

The code found here is a *specification*, rather than an *implementation*. Implementations may choose more efficient versions of these functions. However, all properties of these specifications must be preserved, including strictness properties.

Classes defined in libraries may be derivable. This report includes the derivation of such classes when appropriate. When Prelude types are instances of derivable library classes a commented empty instance declaration is used. The comment, “as derived”, indicates that the instance is the same as would have been generated by a deriving in the Prelude type declaration.

The following table summarises the fixities of all the operators introduced by the standard libraries:

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Table 1: Precedences and fixities of library operators
2 Rational Numbers

module Ratio (Ratio, Fractional, (%), numerator, denominator, approxRational) where

infixl 7 %
data (Integral a) => Ratio a = ...
type Rational = Ratio Integer
(%): (Integral a) => a -> a -> Ratio a
numerator, denominator: (Integral a) => Ratio a -> a
approxRational: (RealFrac a) => a -> a -> Rational
instance (Integral a) => Eq (Ratio a) where ...
instance (Integral a) => Ord (Ratio a) where ...
instance (Integral a) => Num (Ratio a) where ...
instance (Integral a) => Real (Ratio a) where ...
instance (Integral a) => Fractional (Ratio a) where ...
instance (Integral a) => RealFrac (Ratio a) where ...
instance (Integral a) => Enum (Ratio a) where ...
instance (Read a, Integral a) => Read (Ratio a) where ...
instance (Integral a) => Show (Ratio a) where ...

For each Integral type t, there is a type Ratio t of rational pairs with components of type t. The type name Rational is a synonym for Ratio Integer.

Ratio is an instance of classes Eq, Ord, Num, Real, Fractional, RealFrac, Enum, Read, and Show. In each case, the instance for Ratio t simply "lifts" the corresponding operations over t. If t is a bounded type, the results may be unpredictable; for example Ratio Int may give rise to integer overflow even for rational numbers of small absolute size.

The operator (%) forms the ratio of two integral numbers, reducing the fraction to terms with no common factor and such that the denominator is positive. The functions numerator and denominator extract the components of a ratio; these are in reduced form with a positive denominator. Ratio is an abstract type. For example, 12 % 8 is reduced to 3/2 and 12 % (-8) is reduced to (-3)/2.

The approxRational function, applied to two real fractional numbers x and epsilon, returns the simplest rational number within the open interval (x - epsilon, x + epsilon). A rational number n/d in reduced form is said to be simpler than another n'/d' if |n| <= |n'| and d' <= d'. Note that it can be proved that any real interval contains a unique simplest rational.
2.1 Library Ratio

-- Standard functions on rational numbers

module Ratio (Ratio, Rational, (%), numerator, denominator, approxRational) where

infixl 7 %

prec = 7 :: Int

data (Integral a) => Ratio a = !a % !a deriving (Eq)
type Rational = Ratio Integer

(%) :: (Integral a) => a -> a -> Ratio a
numerator, denominator :: (Integral a) => Ratio a -> a
approxRational :: (RealFrac a) => a -> a -> Rational

-- "reduce" is a subsidiary function used only in this module.
-- It normalises a ratio by dividing both numerator
-- and denominator by their greatest common divisor.
--
-- E.g., 12 'reduce' 8 == 3 :% 2
-- 12 'reduce' (-8) == 3 :% (-2)

reduce _ 0 = error "Ratio. % : zero denominator"
reduce x y = (x 'quot' d) :% (y 'quot' d)
where d = gcd x y

x % y = reduce (x * signum y) (abs y)

numerator (x :% _) = x

denominator (_ :% y) = y

instance (Integral a) => Ord (Ratio a) where
  (x :% y) <= (x' :% y') = x * y' <= x' * y
  (x :% y) < (x' :% y') = x * y' < x' * y

instance (Integral a) => Num (Ratio a) where
  (x :% y) + (x' :% y') = reduce (x*y' + x'*y) (y*y')
  (x :% y) * (x' :% y') = reduce (x * x') (y * y')
  negate (x :% y) = (-x) % y
  abs (x :% y) = abs x :% y
  signum (x :% y) = signum x :% 1
  fromInteger x = fromInteger x :% 1

instance (Integral a) => Real (Ratio a) where
  toRational (x :% y) = toInteger x :% toInteger y
instance (Integral a) => Fractional (Ratio a) where
  (x:%y) / (x':%y') = (x*y') % (y*x')
  recip (x:%y) = if x < 0 then (-y) :% (-x) else y :% x
  fromRational (x:%y) = fromInteger x :% fromInteger y

instance (Integral a) => RealFrac (Ratio a) where
  properFraction (x:%y) = (fromIntegral q, r:%y)
    where (q,r) = quotRem x y

instance (Integral a) => Enum (Ratio a) where
  toEnum      = fromInteger
  fromEnum    = fromInteger . truncate      -- May overflow
  enumFrom    = numericEnumFrom
    -- These numericEnumXXX functions
  enumFromThen = numericEnumFromThen
    -- are as defined in Prelude.hs
  enumFromTo  = numericEnumFromTo
    -- but not exported from it!
  enumFromThenTo = numericEnumFromThenTo

instance (Read a, Integral a) => Read (Ratio a) where
  readsPrec p = readParen (p > prec)
    (\r -> [(x:%y,u) | (x,s) <- reads r,
             ("%",t) <- lex s,
             (y,u)  <- reads t ])

instance (Integral a) => Show (Ratio a) where
  showsPrec p (x:%y) = showParen (p > prec)
    (shows x . showString " % " . shows y)

approxRational x eps = simplest (x-eps) (x+eps)
  where simplest x y | y < x    = simplest y x
                   | x == y   = x
                   | x > 0    = simplest n d n' d'
                   | y < 0    = - simplest (-n') d' (-n) d
                   | otherwise = 0 :% 1
    where xr@(n:%d) = toRational x
          (n':%d') = toRational y

  simplest' n d n' d' -- assumes 0 < n%d < n'%'d'
    | r == 0   = q :% 1
    | q /= q'  = (q+1) :% 1
    | otherwise = (q*n' + d') :% n''
    where (q,r) = quotRem n d
          (q',r') = quotRem n' d'
          (n'':%d'') = simplest' d' r' d r
3 Complex Numbers

module Complex (  
    Complex((:+)), realPart, imagPart, conjugate,  
    mkPolar, cis, polar, magnitude, phase ) where

infix 6 :+
data (RealFloat a) => Complex a = !a :+ !a

realPart, imagPart :: (RealFloat a) => Complex a -> a
conjugate :: (RealFloat a) => Complex a -> Complex a
mkPolar :: (RealFloat a) => a -> a -> Complex a
cis :: (RealFloat a) => a -> Complex a
polar :: (RealFloat a) => Complex a -> (a,a)
magnitude, phase :: (RealFloat a) => Complex a -> a

instance (RealFloat a) => Eq (Complex a) where ...
instance (RealFloat a) => Read (Complex a) where ...
instance (RealFloat a) => Show (Complex a) where ...
instance (RealFloat a) => Num (Complex a) where ...
instance (RealFloat a) => Fractional (Complex a) where ...
instance (RealFloat a) => Floating (Complex a) where ...

Complex numbers are an algebraic type. The constructor (:+) forms a complex number from its real and imaginary rectangular components. This constructor is strict: if either the real part or the imaginary part of the number is ⊥, the entire number is ⊥. A complex number may also be formed from polar components of magnitude and phase by the function mkPolar. The function cis produces a complex number from an angle t. Put another way, cis t is a complex value with magnitude 1 and phase t (modulo 2π).

The function polar takes a complex number and returns a (magnitude, phase) pair in canonical form: The magnitude is nonnegative, and the phase, in the range (−π,π]; if the magnitude is zero, then so is the phase.

The functions realPart and imagPart extract the rectangular components of a complex number and the functions magnitude and phase extract the polar components of a complex number. The function conjugate computes the conjugate of a complex number in the usual way.

The magnitude and sign of a complex number are defined as follows:

abs z = magnitude z :: 0
signum 0 = 0
signum z@(x:+y) = x/r :: y/r where r = magnitude z

That is, abs z is a number with the magnitude of z, but oriented in the positive real
direction, whereas signum \( z \) has the phase of \( z \), but unit magnitude.

3.1 Library Complex

module Complex(Complex((:+)), realPart, imagPart, conjugate, mkPolar, 
cis, polar, magnitude, phase) where

infix 6 :+: 
data (RealFloat a) => Complex a = !a :+: !a deriving (Eq, Read, Show) 

realPart, imagPart :: (RealFloat a) => Complex a -> a 
realPart (x:+y) = x 
imagPart (x:+y) = y 

conjugate :: (RealFloat a) => Complex a -> Complex a 
conjugate (x:+y) = x :+: (-y) 

mkPolar :: (RealFloat a) => a -> a -> Complex a 
mkPolar r theta = r * cos theta :+: r * sin theta 

cis :: (RealFloat a) => a -> Complex a 
cis theta = cos theta :+: sin theta 

cis theta = cos theta :+: sin theta 

cis theta = cos theta :+: sin theta 

polar :: (RealFloat a) => Complex a -> (a,a) 
polar z = (magnitude z, phase z) 

magnitude :: (RealFloat a) => Complex a -> a 
magnitude (x:+y) = scaleFloat k 
  (sqrt ((scaleFloat mk x)^2 + (scaleFloat mk y)^2)) 
  where k = max (exponent x) (exponent y) 
    mk = - k 

phase :: (RealFloat a) => Complex a -> a 
phase (0 :+: 0) = 0 
phase (x :+: y) = atan2 y x 

instance (RealFloat a) => Num (Complex a) where 
  (x:+y) + (x'::+y') = (x+x') :+: (y+y') 
  (x:+y) - (x'::+y') = (x-x') :+: (y-y') 
  (x:+y) * (x'::+y') = (x*x'-y*y') :+: (x*y'+y*x') 
  negate (x:+y) = negate x :+: negate y 
  abs z = magnitude z :+: 0 
  signum 0 = 0 
  signum z@ (x:+y) = x/r :+: y/r where r = magnitude z 
  fromInteger n = fromInteger n :+: 0
instance (RealFloat a) => Fractional (Complex a) where
  (x:+y) / (x'+:+y') = (x*x'+y*y') / d :+ ((y*x'-x*y') / d
  where x'' = scaleFloat k x'
  y'' = scaleFloat k y'
  k = - max (exponent x') (exponent y')
  d = x'*x'' + y'*y''

fromRational a = fromRational a :+ 0

instance (RealFloat a) => Floating (Complex a) where
  pi = pi :+ 0
  exp (x:+y) = expx * cos y :+ expx * sin y
    where expx = exp x
  log z = log (magnitude z) :+ phase z
  sqrt 0 = 0
  sqrt z@x:+y) = u :+ (if y < 0 then -v else v)
    where (u,v) = if x < 0 then (v',u') else (u',v')
      v' = abs y / (u''*2)
      u' = sqrt ((magnitude z + abs x) / 2)
  sin (x:+y) = sin x * cosh y :+ cos x * sinh y
  cos (x:+y) = cos x * cosh y :+ (- sin x * sinh y)
  tan (x:+y) = (sinx*coshy:+cosx*sinhy)/(cosx*coshy:+(-sinx*sinhy))
    where sinx = sin x
        cosx = cos x
        sinh = sinh y
        coshy = cosh y
  sinh (x:+y) = cos y * sinh x :+ sin y * cosh x
  cosh (x:+y) = cos y * cosh x :+ sin y * sinh x
  tanh (x:+y) = (cosy*sinhx:+siny*coshx)/(cosy*coshx:+siny*sinhx)
    where siny = sin y
        cosy = cos y
        sinh = sinh x
        coshx = cosh x

  asin z@x:+y) = y':+(-x')
    where (x'+:+y') = log ((-y):+:x) + sqrt (1 - z*z)
  acos z@x:+y) = y'':+(-x'')
    where (x'':+:+y'') = log (z + ((-y'):+x'))
      (x'+:+y') = sqrt (1 - z*z)
  atan z@x:+y) = y':+(-x')
    where (x'+:+y') = log (((1-y):+:x) / sqrt (1+z*z))
  asinh z = log (z + sqrt (1+z*z))
  acosh z = log (z + (z+1) * sqrt ((z-1)/(z+1)))
  atanh z = log ((1+z) / sqrt (1-z*z))
4 Numeric

```haskell
module Numeric(fromRat,
    showSigned, showInt,
    readSigned, readInt,
    readDec, readOct, readHex,
    floatToDigits,
    showEFloat, showFFloat, showGFloat, showFloat,
    readFloat, lexDigits) where

fromRat :: (RealFloat a) => Rational -> a
showSigned :: (Real a) => (a -> ShowS) -> Int -> a -> ShowS
showInt :: Integral a => a -> ShowS
readSigned :: (Real a) => ReadS a -> ReadS a
readInt :: (Integral a) =>
    a -> (Char -> Bool) -> (Char -> Int) -> ReadS a
readDec :: (Integral a) => ReadS a
readOct :: (Integral a) => ReadS a
readHex :: (Integral a) => ReadS a
showEFloat :: (RealFloat a) => Maybe Int -> a -> ShowS
showFFloat :: (RealFloat a) => Maybe Int -> a -> ShowS
showGFloat :: (RealFloat a) => Maybe Int -> a -> ShowS
showFloat :: (RealFloat a) => a -> ShowS
floatToDigits :: (RealFloat a) => Integer -> a -> ([Int], Int)
readFloat :: (RealFloat a) => ReadS a
lexDigits :: ReadS String
```

This library contains assorted numeric functions, many of which are used in the standard Prelude. Most are self-explanatory. The `floatToDigits` function converts a floating point value into a series of digits and an exponent of a selected base. This is used to build a set of floating point formatting functions.

4.1 Library Numeric

```haskell
module Numeric(fromRat,
    showSigned, showInt,
    readSigned, readInt,
    readDec, readOct, readHex,
    floatToDigits,
    showEFloat, showFFloat, showGFloat, showFloat,
    readFloat, lexDigits) where
```
import Char
import Ratio
import Array

-- This converts a rational to a floating. This should be used in the
-- Fractional instances of Float and Double.
fromRat :: (RealFloat a) => Rational -> a
fromRat x =
  if x == 0 then encodeFloat 0 0 -- Handle exceptional cases
  else if x < 0 then - fromRat' (-x) -- first.
  else fromRat' x

-- Conversion process:
-- Scale the rational number by the RealFloat base until
-- it lies in the range of the mantissa (as used by decodeFloat/encodeFloat).
-- Then round the rational to an Integer and encode it with the exponent
-- that we got from the scaling.
-- To speed up the scaling process we compute the log2 of the number to get
-- a first guess of the exponent.
fromRat' :: (RealFloat a) => Rational -> a
fromRat' x = r

where b = floatRadix r
      p = floatDigits r
      (minExp0, _) = floatRange r
      minExp = minExp0 - p -- the real minimum exponent
      minX = toRational (expt b (p-1))
      maxX = toRational (expt b p)
      p0 = (integerLogBase b (numerator x) -
           integerLogBase b (denominator x) - p) `max` minExp
      f = if p0 < 0 then 1 \% expt b (-p0) else expt b p0 \% 1
      (x', p') = scaleRat (toRational b) minExp minX maxX p0 (x / f)
      r = encodeFloat (round x') p'

-- Scale x until minX <= x < maxX, or p (the exponent) <= minExp.
scaleRat :: Rational -> Int -> Rational -> Rational ->
           Int -> Rational -> (Rational, Int)
scaleRat b minExp minX maxX p x =
  if p <= minExp then
    (x, p)
  else if x >= maxX then
    scaleRat b minExp minX maxX (p+1) (x/b)
  else if x < minX then
    scaleRat b minExp minX maxX (p-1) (x*b)
  else
    (x, p)
4.1 Library Numeric

-- Exponentiation with a cache for the most common numbers.
minExpt = 0::Int
maxExpt = 1100::Int
expt :: Integer -> Int -> Integer
expt base n =
    if base == 2 && n >= minExpt && n <= maxExpt then
        expts!n
    else
        base^n

expts :: Array Int Integer
expts = array (minExpt,maxExpt) [(n,2^n) | n <- [minExpt .. maxExpt]]

-- Compute the (floor of the) log of i in base b.
-- Simplest way would be just divide i by b until it's smaller than b,
-- but that would be very slow! We are just slightly more clever.
integerLogBase :: Integer -> Integer -> Int
integerLogBase b i =
    if i < b then
        0
    else
        -- Try squaring the base first to cut down the number of divisions.
        let l = 2 * integerLogBase (b*b) i
            doDiv :: Integer -> Int -> Int
                doDiv i l = if i < b then l else doDiv (i `div` b) (l+1)
                in doDiv (i `div` (b^l)) l

-- Misc utilities to show integers and floats
showSigned :: Real a => (a -> ShowS) -> Int -> a -> ShowS
showSigned showPos p x | x < 0 = showParen (p > 6)
    (showChar '−' . showPos (−x))
    | otherwise = showPos x

-- showInt is used for positive numbers only
showInt :: Integral a => a -> ShowS
showInt n r | n < 0 = error "Numeric.showInt: can’t show negative numbers"
            | otherwise =
                let (n',d) = quotRem n 10
                    r' = toEnum (fromEnum '0' + fromIntegral d) : r
                in if n' == 0 then r' else showInt n' r'
readSigned :: (Real a) => ReadS a | ReadS a
readSigned readPos = readParen False read'
    where read' r = read'' r ++
        [(x,t) | ("-",s) <- lex r,
            (x,t) <- read'' s]
    read'' r = [(n,s) | (str,s) <- lex r,
            (n,"" ) <- readPos str]

-- readInt reads a string of digits using an arbitrary base.
-- Leading minus signs must be handled elsewhere.
readInt :: (Integral a) => a -> (Char -> Bool) -> (Char -> Int) -> ReadS a
readInt radix isDig digToInt s =
    [(foldl1 (\ d -> n * radix + d) (map (fromIntegral . digToInt) ds), r)
        | (ds,r) <- nonnull isDig s ]

-- Unsigned readers for various bases
readDec, readOct, readHex :: (Integral a) => ReadS a
readDec = readInt 10 isDigit digitToInt
readOct = readInt 8 isOctDigit digitToInt
readHex = readInt 16 isHexDigit digitToInt

showEFloat :: (RealFloat a) => Maybe Int -> a -> ShowS
showFFloat :: (RealFloat a) => Maybe Int -> a -> ShowS
showGFloat :: (RealFloat a) => Maybe Int -> a -> ShowS
showFloat :: (RealFloat a) => a -> ShowS

showEFloat d x = showString (formatRealFloat FFExponent d x)
showFFloat d x = showString (formatRealFloat FFFixed d x)
showGFloat d x = showString (formatRealFloat FFGeneric d x)
showFloat = showGFloat Nothing

-- These are the format types. This type is not exported.
data FFFormat = FFExponent | FFFixed | FFGeneric
formatRealFloat :: (RealFloat a) => FFFFormat -> Maybe Int -> a -> String
formatRealFloat fmt decs x = s
    where base = 10
        s = if isNaN x then
            "NaN"
        else if isInfinite x then
            if x < 0 then "-Infinity" else "Infinity"
        else if x < 0 || isNaNZero x then
            '-' : doFmt fmt (floatToDigits (toInt base) (-x))
        else
            doFmt fmt (floatToDigits (toInt base) x)
        doFmt fmt (is, e) =
            let ds = map intToDigit is
                in case fmt of
                    FFGeneric ->
                        doFmt (if e < 0 || e > 7 then FFExponent else FFFixed)
                            (is, e)
                    FFExponent ->
                        case decs of
                            Nothing ->
                                case ds of
                                    ['0'] -> "0.0e0"
                                    [d] -> d : ".0e" ++ show (e-1)
                                    d:ds -> d : '.' : ds ++ 'e':show (e-1)
                                Just dec ->
                                    let dec' = max dec 1 in
                                    case is of
                                        [0] -> '0':'.':take dec' (repeat '0') ++ "e0"
                                    _ ->
                                        let (ei, is') = roundTo base (dec'+1) is
                                            d:ds = map intToDigit
                                            (if ei > 0 then init is' else is')
                                        in d:'.':ds ++ "e" ++ show (e-1+ei)
                    FFFixed ->
                        case decs of
                            Nothing ->
                                let f 0 s ds = mk0 s ++ "." ++ mk0 ds
                                    f n s "" = f (n-1) (s++"0") ""
                                    f n s (d:ds) = f (n-1) (s++[d]) ds
                                    mk0 "" = "0"
                                    mk0 s = s
                                in f e "" ds
                            Just dec ->
                                let dec' = max dec 0 in
if e >= 0 then
    let (ei, is') = roundTo base (dec' + e) is
        (ls, rs) = splitAt (e+ei) (map intToDigit is')
    in (if null ls then "0" else ls) ++
        (if null rs then "" else '.': : rs)
else
    let (ei, is') = roundTo base dec'
        (replicate (-e) 0 ++ is)
    in d : ds = map intToDigit
        (if ei > 0 then is' else 0:is')
    in d : '.': : ds

roundTo :: Int -> Int -> [Int] -> (Int, [Int])
roundTo base d is = case f d is of
    (0, is) -> (0, is)
    (1, is) -> (1, 1 : is)
where b2 = base 'div' 2
    f n [] = (0, replicate n 0)
    f 0 (i:_) = (if i >= b2 then 1 else 0, [])
    f d (i:is) =
        let (c, ds) = f (d-1) is
            i' = c + i
        in if i' == base then (1, 0:ds) else (0, i':ds)

--
-- Based on "Printing Floating-Point Numbers Quickly and Accurately"
-- This version uses a much slower logarithm estimator. It should be improved.
-- This function returns a list of digits (Ints in [0..base-1]) and an
-- exponent.

floatToDigits :: (RealFloat a) => Integer -> a -> ([Int], Int)
4.1 Library Numeric

floatToDigits _ 0 = ([0], 0)
floatToDigits base x =
  let (f0, e0) = decodeFloat x
    (minExp0, _) = floatRange x
    p = floatDigits x
    b = floatRadix x
    minExp = minExp0 - p                -- the real minimum exponent
    -- Haskell requires that f be adjusted so denormalized numbers
    -- will have an improbably low exponent. Adjust for this.
    (f, e) = let n = minExp - e0
           in if n > 0 then (f0 'div' (b^n), e0+n) else (f0, e0)

    (r, s, mUp, mDn) =
      if e >= 0 then
        let be = b^e in
        if f == b^(p-1) then
          (f*be*b^2, 2*b, be*b, b)
        else
          (f*be^2, 2, be, be)
      else
        if e > minExp && f == b^(p-1) then
          (f*b^2, b^(-e+1)*2, b, 1)
        else
          (f*2, b^(-e)*2, 1, 1)

    k =
      let k0 =
        if b==2 && base==10 then
          -- logBase 10 2 is slightly bigger than 3/10 so
          -- the following will err on the low side. Ignoring
          -- the fraction will make it err even more.
          -- Haskell promises that p-1 <= logBase b f < p.
          (p - 1 + e0) * 3 'div' 10
        else
          ceiling ((log (fromInteger (f+1)) +
            fromInt e * log (fromInteger b)) /
            log (fromInteger base))

    fixup n =
      if n >= 0 then
        if r + mUp <= expt base n * s then n else fixup (n+1)
      else
        if expt base (-n) * (r + mUp) <= s then n
          else fixup (n+1)

    in fixup k0

gen ds rn siN mUpN mDnN =
let (dn, rn') = (rn * base) 'divMod' sN
mUpN' = mUpN * base
mDnN' = mDnN * base
in case (rn' < mDnN', rn' + mUpN' > sN) of
  (True, False) -> dn : ds
  (False, True) -> dn+1 : ds
  (True, True) -> if rn' * 2 < sN then dn : ds else dn+1 : ds
  (False, False) -> gen (dn:ds) rn' sN mUpN' mDnN'

rds =
  if k >= 0 then
    gen [] r (s * expt base k) mUp mDn
  else
    let bk = expt base (-k)
    in gen [] (r * bk) s (mUp * bk) (mDn * bk)
    in (map toInt (reverse rds), k)

-- This floating point reader uses a less restrictive syntax for floating
-- point than the Haskell lexer. The '.' is optional.
readFloat :: (ReadFloat a) => ReadS a
readFloat r = [(fromRational ((n\%1)*10^-\(k-d)),t) | (n,d,s) <- readFix r,
  (k,t) <- readExp s]
where readFix r = [(read (ds++ds'), length ds', t)
  | (ds,d) <- lexDigits r,
  (ds',t) <- lexFrac d ]

lexFrac ('.':ds) = lexDigits ds
lexFrac s = [("",s)]
readExp (e:s) | e 'elem' "eE" = readExp' s
readExp s = [(0,s)]
readExp' ('-':s) = [(-k,t) | (k,t) <- readDec s]
readExp' ('+':s) = readDec s
readExp' s = readDec s

lexDigits :: ReadS String
lexDigits = nonnull isDigit

nonnull :: (Char -> Bool) -> ReadS String
nonnull p s = [(cs,t) | (cs\(_\),t) <- [span p s]]
5 Indexing Operations

module Ix (Ix(range, index, inRange), rangeSize) where

class (Ord a) => Ix a where
  range :: (a,a) -> [a]
  index :: (a,a) -> a -> Int
  inRange :: (a,a) -> a -> Bool

rangeSize :: (Ix a) => (a,a) -> Int

instance Ix Char where ...
instance Ix Int where ...
instance Ix Integer where ...
instance (Ix a, Ix b) => Ix (a,b) where ...
-- et cetera
instance Ix Bool where ...
instance Ix Ordering where ...

The Ix class is used to map a continuous subrange of values in a type onto integers. It is used primarily for array indexing (see Section 6). The Ix class contains the methods range, index, and inRange. The index operation maps a bounding pair, which defines the lower and upper bounds of the range, and a subscript, to an integer. The range operation enumerates all subscripts; the inRange operation tells whether a particular subscript lies in the range defined by a bounding pair.

An implementation is entitled to assume the following laws about these operations:

\[
\text{range } (1, u) !\sqcup \text{index } (1, u) i == i \quad \text{-- when i is in range}
\]

\[
\text{inRange } (1, u) i == i \text{ 'elem' range } (1, u)
\]

5.1 Deriving Instances of Ix

Derived instance declarations for the class Ix are only possible for enumerations (i.e. datatypes having only nullary constructors) and single-constructor datatypes, including arbitrarily large tuples, whose constituent types are instances of Ix.

* For an enumeration, the nullary constructors are assumed to be numbered left-to-right with the indices being 0 to \( n - 1 \) inclusive. This is the same numbering defined by the Enum class. For example, given the datatype:

\[
\text{data Colour = Red | Orange | Yellow | Green | Blue | Indigo | Violet}
\]

we would have:
instance (Ix a, Ix b) => Ix (a,b) where
  range ((l, l'), (u, u'))
    = [(i, i') | i <- range (l, u), i' <- range (l', u')]
  index ((l, l'), (u, u')) (i, i')
    = index (l, u) i * rangeSize (l', u') + index (l', u') i'
  inRange ((l, l'), (u, u')) (i, i')
    = inRange (l, u) i && inRange (l', u') i'

-- Instances for other tuples are obtained from this scheme:
--
-- instance (Ix a1, Ix a2, ..., Ix ak) => Ix (a1,a2,...,ak) where
-- range ((l1, l2, ..., lk), (u1, u2, ..., uk)) =
--   [(i1, i2, ..., ik) | i1 <- range (l1, u1),
--     i2 <- range (l2, u2),
--     ...
--     ik <- range (lk, uk)]
--
-- index ((l1, l2, ..., lk), (u1, u2, ..., uk)) (i1, i2, ..., ik) =
-- index (lk, uk) ik + rangeSize (lk, uk) * (index (lk-1, uk-1) ik-1 + rangeSize (lk-1, uk-1) * (...
--     ...
--     index (l1, u1))))
--
-- inRange ((l1, l2, ..., lk), (u1, u2, ..., uk)) (i1, i2, ..., ik) =
-- inRange (l1, u1) i1 && inRange (l2, u2) i2 &&
--     ...
--     && inRange (lk, uk) ik

Figure 1: Derivation of Ix instances

range (Yellow, Blue) == [Yellow, Green, Blue]
index (Yellow, Blue) Green == 1
inRange (Yellow, Blue) Red == False

* For single-constructor datatypes, the derived instance declarations are as shown for tuples in Figure 1.
5.2 Library Ix

module Ix (Ix(range, index, inRange), rangeSize) where

class (Ord a) => Ix a where
  range :: (a, a) -> [a]
  index :: (a, a) -> a -> Int
  inRange :: (a, a) -> a -> Bool

rangeSize :: Ix a => (a, a) -> Int
rangeSize b@(l, h) | null (range b) = 0
  | otherwise = index b h + 1
  -- NB: replacing "null (range b)" by "l > h" fails if
  -- the bounds are tuples. For example,
  -- (2,1) > (1,2),
  -- but
  -- range ((2,1),(1,2)) = []

instance Ix Char where
  range (m, n) = [m..n]
  index b@(c, c') ci
    | inRange b ci = fromEnum ci - fromEnum c
    | otherwise = error "Ix.index: Index out of range."
  inRange (c, c') i = c <= i && i <= c'

instance Ix Int where
  range (m, n) = [m..n]
  index b@(m, n) i
    | inRange b i = i - m
    | otherwise = error "Ix.index: Index out of range."
  inRange (m, n) i = m <= i && i <= n

instance Ix Integer where
  range (m, n) = [m..n]
  index b@(m, n) i
    | inRange b i = fromInteger (i - m)
    | otherwise = error "Ix.index: Index out of range."
  inRange (m, n) i = m <= i && i <= n

instance (Ix a, Ix b) => Ix (a, b) -- as derived, for all tuples
instance Ix Bool -- as derived
instance Ix Ordering -- as derived
instance Ix () -- as derived
6 Arrays

```
module Array (
    module Ix, -- export all of Ix for convenience
    Array, array, listArray, (!), bounds, indices, elems, assoc,
    accumulateArray, (/\), accum, ixmap ) where

import Ix

infixl 9 !, //

data (Ix a) => Array a b = ... -- Abstract

array :: (Ix a) => (a,a) -> [(a,b)] -> Array a b
listArray :: (Ix a) => (a,a) -> [b] -> Array a b
(!) :: (Ix a) => Array a b -> a -> b
bounds :: (Ix a) => Array a b -> (a,a)
indices :: (Ix a) => Array a b -> [a]
elems :: (Ix a) => Array a b -> [b]
assoc :: (Ix a) => Array a b -> [(a,b)]
accumulateArray :: (Ix a) => (b -> c -> b) -> b -> (a,a) -> [(a,c)]
                     -> Array a b
(//) :: (Ix a) => Array a b -> [(a,b)] -> Array a b
accum :: (Ix a) => (b -> c -> b) -> Array a b -> [(a,c)]
         -> Array a b
ixmap :: (Ix a, Ix b) => (a,a) -> (a -> b) -> Array a b
             -> Array a c

instance Functor (Array a) where ...
instance (Ix a, Eq b) => Eq (Array a b) where ...
instance (Ix a, Ord b) => Ord (Array a b) where ...
instance (Ix a, Show a, Show b) => Show (Array a b) where ...
instance (Ix a, Read a, Read b) => Read (Array a b) where ...
```

Haskell provides indexable arrays, which may be thought of as functions whose domains are isomorphic to contiguous subsets of the integers. Functions restricted in this way can be implemented efficiently; in particular, a programmer may reasonably expect rapid access to the components. To ensure the possibility of such an implementation, arrays are treated as data, not as general functions.

Since most array functions involve the class Ix, this module is exported from Array so that modules need not import both Array and Ix.
6.1 Array Construction

If a is an index type and b is any type, the type of arrays with indices in a and elements in b is written Array a b. An array may be created by the function array. The first argument of array is a pair of bounds, each of the index type of the array. These bounds are the lowest and highest indices in the array, in that order. For example, a one-origin vector of length 10 has bounds (1,10), and a one-origin 10 by 10 matrix has bounds ((1,1),(10,10)).

The second argument of array is a list of associations of the form (index, value). Typically, this list will be expressed as a comprehension. An association (i, x) defines the value of the array at index i to be x. The array is undefined (i.e. ⊥) if any index in the list is out of bounds. If any two associations in the list have the same index, the value at that index is undefined (i.e. ⊥). Because the indices must be checked for these errors, array is strict in the bounds argument and in the indices of the association list, but nonstrict in the values. Thus, recurrences such as the following are possible:

\[
\text{a} = \text{array } (1,100) ((1,1) : [(i, i * a!(i-1)) | i <- [2..100]])
\]

Not every index within the bounds of the array need appear in the association list, but the values associated with indices that do not appear will be undefined. Figure 2 shows some examples that use the array constructor.

The (!) operator denotes array subscripting. The bounds function applied to an array returns its bounds. The functions indices, elems, and assocs, when applied to an array, return lists of the indices, elements, or associations, respectively, in index order. An array may be constructed from a pair of bounds and a list of values in index order using the function listArray.
If, in any dimension, the lower bound is greater than the upper bound, then the array is legal, but empty. Indexing an empty array always gives an array-bounds error, but bounds still yields the bounds with which the array was constructed.

### 6.1.1 Accumulated Arrays

Another array creation function, `accumArray`, relaxes the restriction that a given index may appear at most once in the association list, using an *accumulating function* which combines the values of associations with the same index. The first argument of `accumArray` is the accumulating function; the second is an initial value; the remaining two arguments are a bounds pair and an association list, as for the `array` function. For example, given a list of values of some index type, `hist` produces a histogram of the number of occurrences of each index within a specified range:

```plaintext
hist :: (Ix a, Num b) => (a,a) -> [a] -> Array a b

hist bnds is = accumArray (+) 0 bnds [(i, 1) | i<-is, inRange bnds i]
```

If the accumulating function is strict, then `accumArray` is strict in the values, as well as the indices, in the association list. Thus, unlike ordinary arrays, accumulated arrays should not in general be recursive.

### 6.2 Incremental Array Updates

The operator `(/\)` takes an array and a list of pairs and returns an array identical to the left argument except that it has been updated by the associations in the right argument. (As with the `array` function, the indices in the association list must be unique for the updated elements to be defined.) For example, if `m` is a 1-origin, `n` by `n` matrix, then `m/\[[(i,i), 0) \mid i \leftarrow [1..n]]` is the same matrix, except with the diagonal zeroed.

`accum f` takes an array and an association list and accumulates pairs from the list into the array with the accumulating function `f`. Thus `accumArray` can be defined using `accum`:

```plaintext
accumArray f z b = accum f (array b [(i, z) \mid i \leftarrow \text{range } b])
```

### 6.3 Derived Arrays

The two functions `map` and `ixmap` derive new arrays from existing ones; they may be thought of as providing function composition on the left and right, respectively, with the mapping that the original array embodies. The `map` function transforms the array values while `ixmap` allows for transformations on array indices. Figure 3 shows some examples.
6.4 Library Array

module Array (  
  module Ix, -- export all of Ix  
  Array, array, listArray, (!), bounds, indices, elems, assocs,  
  accArray, (//), acc, ixmap ) where

import Ix
import List( (\\) )

infixl 9  !, //

data (Ix a) => Array a b = MkArray (a,a) (a -> b) deriving ()

array :: (Ix a) => (a,a) -> [(a,b)] -> Array a b
array b ivs =
  if and [inRange b i | (i,_) <- ivs]
    then MkArray b
       (\j -> case [v | (i,v) <- ivs, i == j] of
          [v] -> v
          [] -> error "Array.!: \  
                 \undefined array element"
          _ -> error "Array.!: \  
                 \multiply defined array element")
  else error "Array.array: out-of-range array association"

listArray :: (Ix a) => (a,a) -> [b] -> Array a b
listArray b vs = array b (zipWith (\ a b -> (a,b)) (range b) vs)

Figure 3: Derived array examples
(!) :: (Ix a) => Array a b -> a -> b
(!) (MkArray _ f) = f

bounds :: (Ix a) => Array a b -> (a,a)
bounds (MkArray b _) = b

indices :: (Ix a) => Array a b -> [a]
indices = range . bounds
elems :: (Ix a) => Array a b -> [b]
elems a = [a!i | i <- indices a]

assocs :: (Ix a) => Array a b -> [(a,b)]
assocs a = [(i, a!i) | i <- indices a]

(/\) :: (Ix a) => Array a b -> [(a,b)] -> Array a b
a // us = array (bounds a)
          (((i,a!i) | i <- indices a \\ [i | (i,_) <- us])
           ++ us)

accum :: (Ix a) => (b -> c -> b) -> Array a b -> [(a,c)]
       -> Array a b
accum f = foldl (\a (i,v) -> a \ [(i,f (a!i) v)])

accumArray :: (Ix a) => (b -> c -> b) -> b -> (a,a) -> [(a,c)]
            -> Array a b
accumArray f z b = accum f (array b [(i,z) | i <- range b])

ixmap :: (Ix a,Ix b) => (a,a) -> (a -> b) -> Array b c
       -> Array a c
ixmap b f a = array b [(i, a ! f i) | i <- range b]

instance (Ix a) => Functor (Array a) where
      fmap fn (MkArray b f) = MkArray b (fn . f)

instance (Ix a, Eq b) => Eq (Array a b) where
        a == a' = assocs a == assocs a'

instance (Ix a, Ord b) => Ord (Array a b) where
        a <= a' = assocs a <= assocs a'

instance (Ix a, Show a, Show b) => Show (Array a b) where
      showsPrec p a = showParen (p > 9) (showString "array ".
                      shows (bounds a) . showChar ',' .
                      shows (assocs a))
instance (Ix a, Read a, Read b) => Read (Array a b) where
  readsPrec p = readParen (p > 9)
  (\r -> [(array b as, u) | ("array",s) <- lex r,
  (b,t)   <- reads s,
  (as,u)  <- reads t ])


module List (  
elemIndex, elemIndices,  
find, findIndex, findIndices,  
nub, nubBy, delete, deleteBy, (\\), deleteFirstsBy,  
uunion, unionBy, intersect, intersectBy,  
intersperse, transpose, partition, group, groupBy,  
inits, tails, isPrefixOf, isSuffixOf,  
mapAccumL, mapAccumR,  
sort, sortBy, insert, insertBy, maximumBy, minimumBy,  
genericLength, genericTake, genericDrop,  
genericSplitAt, genericIndex, genericReplicate,  
zip4, zip5, zip6, zip7,  
zipWith4, zipWith5, zipWith6, zipWith7,  
unzip4, unzip5, unzip6, unzip7, unfoldr,  
)  

-- ...and what the Prelude exports  
[[], [], map, (++)], concat, filter,  
head, last, tail, init, null, length, (!!!),  
foldl, foldl1, scanl, scanl1, foldr, foldr1, scanr, scanr1,  
iterate, repeat, replicate, cycle,  
take, drop, splitAt, takeWhile, dropWhile, span, break,  
lines, words, unlines, unwords, reverse, and, or,  
any, all, elem, notElem, lookup,  
sum, product, maximum, minimum, concatMap,  
zip, zip3, zipWith, zipWith3, unzip, unzip3  
) where  
  infix 5 \"  
elemIndex :: Eq a => a -> [a] -> Maybe Int  
elemIndices :: Eq a => a -> [a] -> [Int]  
find :: (a -> Bool) -> [a] -> Maybe a  
findIndex :: (a -> Bool) -> [a] -> Maybe Int  
findIndices :: (a -> Bool) -> [a] -> [Int]  
nub :: Eq a => [a] -> [a]  
nubBy :: (a -> a -> Bool) -> [a] -> [a]  
delete :: Eq a => a -> [a] -> [a]  
deleteBy :: (a -> a -> Bool) -> a -> [a] -> [a]  
(\\) :: Eq a => [a] -> [a] -> [a]  
deleteFirstsBy :: (a -> a -> Bool) -> [a] -> [a] -> [a]  
uunion :: Eq a => [a] -> [a] -> [a]  
uunionBy :: (a -> a -> Bool) -> [a] -> [a] -> [a]
<table>
<thead>
<tr>
<th>Function</th>
<th>Type</th>
</tr>
</thead>
<tbody>
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<td>intersect</td>
<td>Eq a =&gt; [a] -&gt; [a] -&gt; [a]</td>
</tr>
<tr>
<td>intersectBy</td>
<td>(a -&gt; a -&gt; Bool) -&gt; [a] -&gt; [a] -&gt; [a]</td>
</tr>
<tr>
<td>intersperse</td>
<td>a -&gt; [a] -&gt; [a]</td>
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<tr>
<td>transpose</td>
<td>[[a]] -&gt; [[a]]</td>
</tr>
<tr>
<td>partition</td>
<td>(a -&gt; Bool) -&gt; [a] -&gt; ([a], [a])</td>
</tr>
<tr>
<td>group</td>
<td>Eq a =&gt; [a] -&gt; [[a]]</td>
</tr>
<tr>
<td>groupBy</td>
<td>(a -&gt; a -&gt; Bool) -&gt; [a] -&gt; [[a]]</td>
</tr>
<tr>
<td>inits</td>
<td>[a] -&gt; [[a]]</td>
</tr>
<tr>
<td>tails</td>
<td>[a] -&gt; [[a]]</td>
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<td>Eq a =&gt; [a] -&gt; [a] -&gt; Bool</td>
</tr>
<tr>
<td>isSuffixOf</td>
<td>Eq a =&gt; [a] -&gt; [a] -&gt; Bool</td>
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</tr>
<tr>
<td>mapAccumR</td>
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</tr>
<tr>
<td>unfoldr</td>
<td>(b -&gt; Maybe (a, b)) -&gt; b -&gt; [a]</td>
</tr>
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<td>sort</td>
<td>Ord a =&gt; [a] -&gt; [a]</td>
</tr>
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<td>sortBy</td>
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<td>insert</td>
<td>Ord a =&gt; a -&gt; [a] -&gt; [a]</td>
</tr>
<tr>
<td>insertBy</td>
<td>(a -&gt; a -&gt; Ordering) -&gt; a -&gt; [a] -&gt; [a]</td>
</tr>
<tr>
<td>maximumBy</td>
<td>(a -&gt; a -&gt; Ordering) -&gt; [a] -&gt; a</td>
</tr>
<tr>
<td>minimumBy</td>
<td>(a -&gt; a -&gt; Ordering) -&gt; [a] -&gt; a</td>
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<td>Integral a =&gt; [b] -&gt; a</td>
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<td>genericTake</td>
<td>Integral a =&gt; a -&gt; [b] -&gt; [b]</td>
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<tr>
<td>genericDrop</td>
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</tr>
<tr>
<td>genericSplitAt</td>
<td>Integral a =&gt; a -&gt; [b] -&gt; ([b], [b])</td>
</tr>
<tr>
<td>genericIndex</td>
<td>Integral a =&gt; [b] -&gt; a -&gt; b</td>
</tr>
<tr>
<td>genericReplicate</td>
<td>Integral a =&gt; a -&gt; b -&gt; [b]</td>
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<td>[a] -&gt; [b] -&gt; [c] -&gt; [d] -&gt; [(a, b, c, d)]</td>
</tr>
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<td>zip5</td>
<td>[a] -&gt; [b] -&gt; [c] -&gt; [d] -&gt; [e] -&gt; [(a, b, c, d, e)]</td>
</tr>
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</tr>
<tr>
<td></td>
<td>-&gt; [(a, b, c, d, e, f)]</td>
</tr>
<tr>
<td>zip7</td>
<td>[a] -&gt; [b] -&gt; [c] -&gt; [d] -&gt; [e] -&gt; [f] -&gt; [g]</td>
</tr>
<tr>
<td></td>
<td>-&gt; [(a, b, c, d, e, f, g)]</td>
</tr>
<tr>
<td>zipWith4</td>
<td>(a -&gt; b -&gt; c -&gt; d -&gt; e) -&gt; [a] -&gt; [b] -&gt; [c] -&gt; [d] -&gt; [e]</td>
</tr>
<tr>
<td>zipWith5</td>
<td>(a -&gt; b -&gt; c -&gt; d -&gt; e -&gt; f) -&gt; [a] -&gt; [b] -&gt; [c] -&gt; [d] -&gt; [e] -&gt; [f]</td>
</tr>
<tr>
<td>zipWith6</td>
<td>(a -&gt; b -&gt; c -&gt; d -&gt; e -&gt; f -&gt; g) -&gt; [a] -&gt; [b] -&gt; [c] -&gt; [d] -&gt; [e] -&gt; [f] -&gt; [g]</td>
</tr>
<tr>
<td>zipWith7</td>
<td>(a -&gt; b -&gt; c -&gt; d -&gt; e -&gt; f -&gt; g -&gt; h) -&gt; [a] -&gt; [b] -&gt; [c] -&gt; [d] -&gt; [e] -&gt; [f] -&gt; [g] -&gt; [h]</td>
</tr>
<tr>
<td>unzip4</td>
<td>[(a, b, c, d)] -&gt; ([a], [b], [c], [d])</td>
</tr>
<tr>
<td>unzip5</td>
<td>[(a, b, c, d, e)] -&gt; ([a], [b], [c], [d], [e])</td>
</tr>
<tr>
<td>unzip6</td>
<td>[(a, b, c, d, e, f)] -&gt; ([a], [b], [c], [d], [e], [f])</td>
</tr>
<tr>
<td>unzip7</td>
<td>[(a, b, c, d, e, f, g)] -&gt; ([a], [b], [c], [d], [e], [f], [g])</td>
</tr>
</tbody>
</table>
This library defines some lesser-used operations over lists.

### 7.1 Indexing lists

Function `elemIndex val list` returns the index of the first occurrence, if any, of `val` in `list` as `Just index`. Nothing is returned if not (`val` 'elem' `list`).

Function `elemIndices val list` returns an in-order list of indices, giving the occurrences of `val` in `list`.

Function `find` returns the first element of a list that satisfies a predicate, or `Nothing`, if there is no such element. `findIndex` returns the corresponding index. `findIndices` returns a list of all such indices.

### 7.2 “Set” operations

There are a number of “set” operations defined over the `List` type. `nub` (meaning “essence”) removes duplicates elements from a list. `delete`, `(\`)`, `union` and `intersect` preserve the invariant that lists don’t contain duplicates, provided that their first argument contains no duplicates.

- `delete x` removes the first occurrence of `x` from its list argument, e.g.,
  
  ```
  delete 'a' "banana" == "bnana"
  ```

- `(\`) is list difference (non-associative). In the result of `xs \ ys`, the first occurrence of each element of `ys` in turn (if any) has been removed from `xs`. Thus, `(xs ++ ys) \ xs == ys`. `union` is list union, e.g.,
  
  ```
  "dog" 'union' "cow" == "dogcw"
  ```

- `intersect` is list intersection, e.g.,
  
  ```
  intersect [1,2,3,4] 'intersect' [2,4,6,8] == [2,4]
  ```

### 7.3 List transformations

- `intersperse sep` inserts `sep` between the elements of its list argument, e.g.,
  
  ```
  intersperse ',' "abcde" == "a,b,c,d,e"
  ```
• \texttt{transpose} transposes the rows and columns of its argument, e.g.,
  \[
  \text{transpose } [[1,2,3],[4,5,6]] == [[1,4],[2,5],[3,6]]
  \]

• \texttt{partition} takes a predicate and a list and returns a pair of lists: those elements of
  the argument list that do and do not satisfy the predicate, respectively; i.e.,
  \[
  \text{partition } p \; x s == (\text{filter } p \; x s, \text{filter } (\text{not } . \; p) \; x s)
  \]

• \texttt{sort/sortBy} implement a stable sorting algorithm, here specified in terms of the
  \texttt{insertBy} function, which inserts objects into a list according to the specified ordering
  relation.

• \texttt{group} splits its list argument into a list of lists of equal, adjacent elements. For
  example
  \[
  \text{group } "\text{Mississippi}" == ["M","i","ss","i","ss","i","pp","i"]
  \]

• \texttt{inits} returns the list of initial segments of its argument list, shortest first.
  \[
  \text{inits } "abc" == ["","a","ab","abc"]
  \]

• \texttt{tails} returns the list of all final segments of its argument list, longest first.
  \[
  \text{tails } "abc" == ["abc", "bc", "c", ""]
  \]

• \texttt{mapAccumL} \; f \; s \; l applies \( f \) to an accumulating "state" parameter \( s \) and to each
  element of \( l \) in turn.

• \texttt{mapAccumR} is similar to \texttt{mapAccumL} except that the list is processed from right-to-left
  rather than left-to-right.

7.4 \texttt{unfoldr}

The \texttt{unfoldr} function undoes a \texttt{foldr} operation. Note that, in general, only invertible
functions can be unfolded.

\[
\text{unfoldr } f' \; (\text{foldr } f \; z \; x s) == x s
\]

if the following holds:

\[
\begin{align*}
  f' \; (f \; x \; y) &= \text{Just } (x,y) \\
  f' \; z &= \text{Nothing}
\end{align*}
\]
7.5 Predicates

isPrefixOf and isSuffixOf check whether the first argument is a prefix (resp. suffix) of the second argument.

7.6 The “By” operations

By convention, overloaded functions have a non-overloaded counterpart whose name is suffixed with “By”. For example, the function nub could be defined as follows:

\[
\begin{align*}
nub & : (\text{Eq} \ a) \Rightarrow [a] \rightarrow [a] \\
nub \ [] & = [] \\
nub \ (x:xs) & = x : \ nub \ (\text{filter} \ (\lambda y \rightarrow x \neq y) \ xs)
\end{align*}
\]

However, the equality method may not be appropriate in all situations. The function:

\[
\begin{align*}
nubBy & : (a \rightarrow a \rightarrow \text{Bool}) \Rightarrow [a] \rightarrow [a] \\
nubBy \ \text{eq} \ [] & = [] \\
nubBy \ \text{eq} \ (x:xs) & = x : \ nubBy \ \text{eq} \ (\text{filter} \ (\lambda y \rightarrow \text{not} \ (\text{eq} \ x \ y)) \ xs)
\end{align*}
\]

allows the programmer to supply their own equality test. When the “By” function replaces an Eq context by a binary predicate, the predicate is assumed to define an equivalence; when the “By” function replaces an Ord context by a binary predicate, the predicate is assumed to define a total ordering.

The “By” variants are as follows: nubBy, deleteBy, unionBy, intersectBy, groupBy, sortBy, insertBy, maximumBy, minimumBy. The library does not provide elemBy, because any (eq x) does the same job as elemBy eq x would. A handful of overloaded functions (elemIndex, elemIndices, isPrefixOf, isSuffixOf) were not considered important enough to have “By” variants.

7.7 The “generic” operations

The prefix “generic” indicates an overloaded function that is a generalised version of a Prelude function. For example,

\[
\begin{align*}
genericLength & : \text{Integral} \ a \Rightarrow [b] \rightarrow a
\end{align*}
\]

is a generalised version of length.

The “generic” operations are as follows: genericLength, genericTake, genericDrop, genericSplitAt, genericIndex, genericReplicate.
module List (  
  elemIndex, elemIndices,  
  find, findIndex, findIndices,  
  nub, nubBy, delete, deleteBy, (\\),  
  union, unionBy, intersect, intersectBy,  
  intersperse, transpose, partition, group, groupBy,  
  init, tails, isPrefixOf, isSuffixOf,  
  mapAccumL, mapAccumR,  
  sort, sortBy, insert, insertBy, maximumBy, minimumBy,  
  genericLength, genericTake, genericDrop,  
  genericSplitAt, genericIndex, genericReplicate,  
  zip4, zip5, zip6, zip7,  
  zipWith4, zipWith5, zipWith6, zipWith7,  
  unzip4, unzip5, unzip6, unzip7, unfoldr,  
  -- ...)and what the Prelude exports  
[](()), [],  
map, (++), concat, filter,  
head, last, tail, init, null, length, (!!),  
fold1, foldl1, scanl, scanl1, foldr, foldr1, scanr, scanr1,  
itrate, repeat, replicate, cycle,  
take, drop, splitAt, takeWhile, dropWhile, span, break,  
lines, words, unlines, unwords, reverse, and, or,  
any, all, elem, notElem, lookup,  
sum, product, maximum, minimum, concatMap,  
zip, zip3, zipWith, zipWith3, unzip, unzip3  
) where

import Maybe( listToMaybe )

infix 5 \"  

elemIndex :: Eq a => a -> [a] -> Maybe Int  nelemIndex x = findIndex (x ==)

elemIndices :: Eq a => a -> [a] -> [Int]  nelemIndices x = findIndices (x ==)

find :: (a -> Bool) -> [a] -> Maybe a  
find p = listToMaybe . filter p

findIndex :: (a -> Bool) -> [a] -> Maybe Int  
findIndex p = listToMaybe . findIndices p

findIndices :: (a -> Bool) -> [a] -> [Int]  
findIndices p xs = [i | (x, i) <- zip xs [0..], p x]
nub :: Eq a => [a] -> [a]
    = nubBy (==)

nubBy :: (a -> a -> Bool) -> [a] -> [a]
    = foldl (flip delete) []

deleteBy :: (a -> a -> Bool) -> a -> [a] -> [a]
deleteBy eq x [] = []
deleteBy eq x (y:ys) = if x 'eq' y then ys else y : deleteBy eq x ys

(\\) :: Eq a => [a] -> [a] -> [a]
(\\) = foldl (flip delete) []

deleteFirstsBy :: (a -> a -> Bool) -> [a] -> [a] -> [a]
deleteFirstsBy eq = foldl (flip (deleteBy eq))

union :: Eq a => [a] -> [a] -> [a]
union = unionBy (==)

unionBy :: (a -> a -> Bool) -> [a] -> [a] -> [a]
unionBy eq xs ys = xs ++ foldl (flip (deleteBy eq)) (nubBy eq ys) xs

intersect :: Eq a => [a] -> [a] -> [a]
intersect = intersectBy (==)

intersectBy :: (a -> a -> Bool) -> [a] -> [a] -> [a]
intersectBy eq xs ys = [x | x <- xs, any (eq x) ys]

intersperse :: a -> [a] -> [a]
isintersperse [] = []
isintersperse [x] = [x]
isintersperse (x:xs) = x : sep : intersperse sep xs

-- transpose is lazy in both rows and columns,
-- and works for non-rectangular 'matrices'
-- For example, transpose [[1,2],[3,4,5],[[]]] = [[1,3],[2,4],[5]]
-- Note that [h | (h:t) <- xss] is not the same as (map head xss)
-- because the former discards empty sublists inside xss
transpose :: [[a]] -> [[a]]
transpose [] = []
transpose ([] : xss) = transpose xss
transpose ((x:xs) : xss) = (x : [h | (h:t) <- xss]) :
    transpose (xs : [t | (h:t) <- xss])
partition :: (a → Bool) → [a] → ([a],[a])
partition p xs = foldr select ([],[[]]) xs
    where select x (ts,fs) | p x = (x:ts,fs)
        otherwise = (ts,x:fs)

-- group splits its list argument into a list of lists of equal, adjacent
-- elements. e.g.,
-- group "Mississippi" == ["M","i","ss","i","ss","i","pp","i"]
group :: Eq a ⇒ [a] → [[a]]
group = groupBy (==)
groupBy :: (a → a → Bool) → [a] → [[a]]
groupBy eq [] = []
groupBy eq (x:xs) = (x:ys) : groupBy eq zs
    where (ys,zs) = span (eq x) xs

-- inits xs returns the list of initial segments of xs, shortest first.
-- e.g., inits "abc" == ["","a","ab","abc"]

inits :: [a] → [[a]]
inits [] = [[]]
inits (x:xs) = [[]] ++ map (x:) (inits xs)

tails xs returns the list of all final segments of xs, longest first.
-- e.g., tails "abc" == ["abc", "bc", "c",""]

tails :: [a] → [[a]]
tails [] = [[]]
tails xx @(_:xs) = xx : tails xs

isPrefixOf :: Eq a ⇒ [a] → [a] → Bool
isPrefixOf [] _ = True
isPrefixOf _ [] = False
isPrefixOf (x:xs) (y:ys) = x == y && isPrefixOf xs ys

isSuffixOf :: Eq a ⇒ [a] → [a] → Bool
isSuffixOf x y = reverse x 'isPrefixOf' reverse y

mapAccumL :: (a → b → (a, c)) → a → [b] → (a, [c])
mapAccumL f s [] = (s, [])
mapAccumL f s (x:xs) = (s', y:ys)
    where (s', y) = f s x
        (s', ys) = mapAccumL f s' xs

mapAccumR :: (a → b → (a, c)) → a → [b] → (a, [c])
mapAccumR f s [] = (s, [])
mapAccumR f s (x:xs) = (s', y:ys)
    where (s', y) = f s x
        (s', ys) = mapAccumR f s' xs
unfoldr :: (b -> Maybe (a,b)) -> b -> [a]
unfoldr f b = case f b of
  Nothing  -> []
  Just (a,b) -> a : unfoldr f b

sort :: (Ord a) => [a] -> [a]
sort = sortBy compare

sortBy :: (a -> a -> Ordering) -> [a] -> [a]
s sortBy cmp = foldr (insertBy cmp) []

insert :: (Ord a) => a -> [a] -> [a]
insert = insertBy compare

insertBy :: (a -> a -> Ordering) -> a -> [a] -> [a]
insertBy cmp x [] = [x]
insertBy cmp x ys@(y:ys') = case cmp x y of
  GT -> y : insertBy cmp x ys'
  _  -> x : ys

maximumBy :: (a -> a -> a) -> [a] -> a
maximumBy max [] = error "List.maximumBy: empty list"
maximumBy max xs = foldl1 max xs

minimumBy :: (a -> a -> a) -> [a] -> a
minimumBy min [] = error "List.minimumBy: empty list"
minimumBy min xs = foldl1 min xs

genericLength :: (Integral a) => [b] -> a
genericLength [] = 0
genericLength (x:xs) = 1 + genericLength xs

genericTake :: (Integral a) => a -> [b] -> [b]
genericTake _ [] = []
genericTake 0 _ = []
genericTake n (x:xs)
  | n > 0 = x : genericTake (n-1) xs
  | otherwise = error "List.genericTake: negative argument"

genericDrop :: (Integral a) => a -> [b] -> [b]
genericDrop 0 xs = xs
genericDrop _ [] = []
genericDrop n (_:xs)
  | n > 0 = genericDrop (n-1) xs
  | otherwise = error "List.genericDrop: negative argument"
genericSplitAt :: (Integral a) => a -> b -> [(b,[b])
genericSplitAt 0 xs = ([],xs)
genericSplitAt _ [] = ([],[])
genericSplitAt n (x:xs)
  | n > 0 = (x:xs',xs''')
  | otherwise = error "List.genericSplitAt: negative argument"
  where (xs',xs''') = genericSplitAt (n-1) xs

genericIndex :: (Integral a) => [b] -> a -> b
genericIndex (x:_) 0 = x
genericIndex (_:xs) n
  | n > 0 = genericIndex xs (n-1)
  | otherwise = error "List.genericIndex: negative argument"

genericReplicate :: (Integral a) => a -> b -> [b]
genericReplicate n x = genericTake n (repeat x)

zip4 :: [a] -> [b] -> [c] -> [d] -> [(a,b,c,d)]
zip4 = zipWith4 (,,)

zip5 :: [a] -> [b] -> [c] -> [d] -> [e] -> [(a,b,c,d,e)]
zip5 = zipWith5 (,,)

zip6 :: [a] -> [b] -> [c] -> [d] -> [e] -> [f] ->
     [(a,b,c,d,e,f)]
zip6 = zipWith6 (,,)

zip7 :: [a] -> [b] -> [c] -> [d] -> [e] -> [f] ->
     [g] -> [(a,b,c,d,e,f,g)]
zip7 = zipWith7 (,,)

zipWith4 z (a:as) (b:bs) (c:cs) (d:ds)
  = z a b c d : zipWith4 z as bs cs ds
zipWith4 _ _ _ _ = []

zipWith5 z (a:as) (b:bs) (c:cs) (d:ds) (e:es)
  = z a b c d e : zipWith5 z as bs cs ds es
zipWith5 _ _ _ _ = []

zipWith6 z (a:as) (b:bs) (c:cs) (d:ds) (e:es) (f:fs)
  = z a b c d e f : zipWith6 z as bs cs ds es fs
zipWith6 _ _ _ _ _ _ = []
zipWith7 :: (a->b->c->d->e->f->g->h) -> 
       [a]->[b]->[c]->[d]->[e]->[f]->[g]->[h]
zipWith7 z (a:as) (b:bs) (c:cs) (d:ds) (e:es) (f:fs) (g:gs)
       = z a b c d e f g : zipWith7 z as bs cs ds es fs gs
zipWith7 _ _ _ _ _ _ _ = []
unzip4 :: [(a,b,c,d)] -> ([a],[b],[c],[d])
unzip4 = foldr (\(a,b,c,d) ->
               (a:as,b:bs,c:cs,d:ds))
          (\,\,\,\,\)
unzip5 :: [(a,b,c,d,e)] -> ([a],[b],[c],[d],[e])
unzip5 = foldr (\(a,b,c,d,e) ->
               (a:as,b:bs,c:cs,d:ds,e:es))
          (\,\,\,\,\,\)
unzip6 :: [(a,b,c,d,e,f)] -> ([a],[b],[c],[d],[e],[f])
unzip6 = foldr (\(a,b,c,d,e,f) ->
               (a:as,b:bs,c:cs,d:ds,e:es,f:fs))
          (\,\,\,\,\,\,\)
unzip7 :: [(a,b,c,d,e,f,g)] -> ([a],[b],[c],[d],[e],[f],[g])
unzip7 = foldr (\(a,b,c,d,e,f,g) ->
               (a:as,b:bs,c:cs,d:ds,e:es,f:fs,g:gs))
          (\,\,\,\,\,\,\,\)
8 Maybe Utilities

```haskell
module Maybe(
    isJust, isNothing,
    fromJust, fromMaybe, listToMaybe, maybeToList,
    catMaybes, mapMaybe,
    -- ...and what the Prelude exports
    Maybe(Nothing, Just),
    maybe
) where

isJust, isNothing    :: Maybe a -> Bool
fromJust             :: Maybe a -> a
fromMaybe            :: a -> Maybe a -> a
listToMaybe          :: [a] -> Maybe a
maybeToList          :: Maybe a -> [a]
catMaybes            :: [Maybe a] -> [a]
mapMaybe             :: (a -> Maybe b) -> [a] -> [b]
```

The type constructor Maybe is defined in Prelude as

```haskell
data Maybe a = Nothing | Just a
```

The purpose of the Maybe type is to provide a method of dealing with illegal or optional values without terminating the program, as would happen if error were used, and without using IOError from the IO monad, which would cause the expression to become monadic. A correct result is encapsulated by wrapping it in Just; an incorrect result is returned as Nothing.

Other operations on Maybe are provided as part of the monadic classes in the Prelude.
module Maybe(
    isJust, isNothing,
    fromJust, fromMaybe, listToMaybe, maybeToList,
    catMaybe, mapMaybe,
)

-- ...and what the Prelude exports
Maybe(Nothing, Just),
maybe
)
where

isJust :: Maybe a -> Bool
isJust (Just a) = True
isJust Nothing = False

isNothing :: Maybe a -> Bool
isNothing = not . isJust

fromJust :: Maybe a -> a
fromJust (Just a) = a
fromJust Nothing = error "Maybe.fromJust: Nothing"

fromMaybe :: a -> Maybe a -> a
fromMaybe d Nothing = d
fromMaybe d (Just a) = a

maybeToList :: Maybe a -> [a]
maybeToList Nothing = []
maybeToList (Just a) = [a]

listToMaybe :: [a] -> Maybe a
listToMaybe [] = Nothing
listToMaybe (a:_) = Just a

catMaybees :: [Maybe a] -> [a]
catMaybees ms = [ m | Just m <- ms ]

mapMaybe :: (a -> Maybe b) -> [a] -> [b]
mapMaybe f = catMaybees . map f
9 Character Utilities

```haskell
module Char (  
isAscii, isLatin1, isControl, isPrint, isSpace, isUpper, isLower,  
isAlpha, isDigit, isOctDigit, isHexDigit, isAlphaNum,  
digitToInt, intToDigit,  
toUpper, toLower,  
ord, chr,  
readLitChar, showLitChar, lexLitChar  
) where

isAscii, isLatin1, isControl, isPrint, isSpace, isUpper, isLower,  
isAlpha, isDigit, isOctDigit, isHexDigit, isAlphaNum :: Char -> Bool

toUpper, toLower :: Char -> Char

digitToInt :: Char -> Int

intToDigit :: Int -> Char

ord :: Char -> Int

chr :: Int -> Char

lexLitChar :: ReadS String

readLitChar :: ReadS Char

showLitChar :: Char -> ShowS
```

This library provides a limited set of operations on the Unicode character set. The first 128 entries of this character set are identical to the ASCII set; with the next 128 entries comes the remainder of the Latin-1 character set. This module offers only a limited view of the full Unicode character set; the full set of Unicode character attributes is not accessible in this library.

Unicode characters may be divided into five general categories: non-printing, lower case alphabetic, other alphabetic, numeric digits, and other printable characters. For the purposes of Haskell, any alphabetic character which is not lower case is treated as upper case (Unicode actually has three cases: upper, lower, and title). Numeric digits may be part of identifiers but digits outside the ASCII range are not used by the reader to represent numbers.

For each sort of Unicode character, here are the predicates which return True:
<table>
<thead>
<tr>
<th>Character Type</th>
<th>Predicates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Case Alphabetic</td>
<td>isPrint  isAlphaNum  isAlpha  isLower</td>
</tr>
<tr>
<td>Other Alphabetic</td>
<td>isPrint  isAlphaNum  isAlpha  isUpperc</td>
</tr>
<tr>
<td>Digits</td>
<td>isPrint  isAlphaNum</td>
</tr>
<tr>
<td>Other Printable</td>
<td>isPrint</td>
</tr>
<tr>
<td>Non-printing</td>
<td></td>
</tr>
</tbody>
</table>

The `isDigit`, `isOctDigit`, and `isHexDigit` functions select only ASCII characters. `intToDigit` and `digitToInt` convert between a single digit `Char` and the corresponding `Int`. `digitToInt` operates fails unless its argument satisfies `isHexDigit`, but recognises both upper and lower-case hexadecimal digits (i.e. '0'..'9', 'a'..'f', 'A'..'F'). `intToDigit` fails unless its argument is in the range 0..15, and generates lower-case hexadecimal digits.

The `isSpace` function recognizes only white characters in the Latin-1 range.

The function `showLitChar` converts a character to a string using only printable characters, using Haskell source-language escape conventions. The function `readLitChar` does the reverse.

Function `toUpperCase` converts a letter to the corresponding upper-case letter, leaving any other character unchanged. Any Unicode letter which has an upper-case equivalent is transformed. Similarly, `toLowerCase` converts a letter to the corresponding lower-case letter, leaving any other character unchanged.

The `ord` and `chr` functions are `fromEnum` and `toEnum` restricted to the type `Char`. 
9.1 Library Char

module Char (
    isAscii, isLatin1, isControl, isPrint, isSpace, isUpper, isLower,
    isAlpha, isDigit, isOctDigit, isHexDigit, isAlphaNum,
    digitToInt, intToDigit,
    toUpper, toLower,
    ord, chr,
    readLitChar, showLitChar, lexLitChar,
    -- ...and what the Prelude exports
    Char, String
) where

import Array -- used for character name table.
import Numeric (readDec, readOct, lexDigits, readHex)
import UnicodePrims -- source of primitive Unicode functions.

-- Character-testing operations
isAscii, isControl, isPrint, isSpace, isUpper, isLower,
isAlpha, isDigit, isOctDigit, isHexDigit, isAlphaNum :: Char -> Bool

isAscii c      = c < '\x80'
isLatin1 c     = c <= '\xff'
isControl c    = c < ' ' || c >= '\DEL' && c <= '\x9f'
isPrint        = primUnicodeIsPrint
isSpace c      = c 'elem' " \t\n\r\f\v\xA0"
    -- Only Latin-1 spaces recognized
isUpper        = primUnicodeIsUpper -- 'A'..'Z'
isLower        = primUnicodeIsLower -- 'a'..'z'
isAlpha c      = isUpper c || isLower c
isDigit c      = c >= '0' && c <= '9'
isOctDigit c   = c >= '0' && c <= '7'
isHexDigit c   = isDigit c || c >= 'A' && c <= 'F' ||
                  c >= 'a' && c <= 'f'
isAlphaNum     = primUnicodeIsAlphaNum
-- Digit conversion operations

digitToInt :: Char -> Int
digitToInt c
  | isDigit c = fromEnum c - fromEnum '0'
  | c >= 'a' && c <= 'f' = fromEnum c - fromEnum 'a' + 10
  | c >= 'A' && c <= 'F' = fromEnum c - fromEnum 'A' + 10
  | otherwise = error "Char.digitToInt: not a digit"

intToDigit :: Int -> Char
intToDigit i
  | i >= 0 && i <= 9 = toEnum (fromEnum '0' + i)
  | i >= 10 && i <= 15 = toEnum (fromEnum 'a' + i - 10)
  | otherwise = error "Char.intToDigit: not a digit"

-- Case-changing operations

toUpper :: Char -> Char
toUpper = primUnicodeToUpper

toLower :: Char -> Char
toLower = primUnicodeToLower

-- Character code functions

ord :: Char -> Int
ord = fromEnum

chr :: Int -> Char
chr = toEnum
-- Text functions
readLitChar :: ReadS Char
readLitChar ('\":s) = readEsc s

where
readEsc ('a':s) = [(\'a\',s)]
readEsc ('b':s) = [(\'b\',s)]
readEsc ('f':s) = [(\'f\',s)]
readEsc ('n':s) = [(\'n\',s)]
readEsc ('r':s) = [(\'r\',s)]
readEsc ('t':s) = [(\'t\',s)]
readEsc ('v':s) = [(\'v\',s)]
readEsc ('\":s) = [(\'\":s)]
readEsc ('\":s) = [(\'\":s)]
readEsc ('\':c:s) | c >= '0' && c <= '_'
    = [(chr (ord c - ord '0'), s)]
readEsc s@d:__ | isDigit d
    = [(chr n, t) | (n,t) <- readDec s]
readEsc ('o':s) = [(chr n, t) | (n,t) <- read0ct s]
readEsc ('x':s) = [(chr n, t) | (n,t) <- readHex s]
readEsc s@c:__ | isUpper c
    = let table = (\'DEL\', "DEL") : assocs asciiTab
        in case [(c,s')] | (c, mne) <- table,
                  ([],s') <- [match mne s]]
        of (pr:_)) -> [pr]
            [] -> []
readEsc _ = []

match :: (Eq a) => [a] -> [a] -> ([a],[a])
match (x:xs) (y:ys) | x == y = match xs ys
match xs    ys       = (xs,ys)
readLitChar (c:s) = [(c,s)]
9.1  Library Char

showLitChar :: Char -> ShowS
showLitChar c | c > '\ DEL' = showChar '\'
                = protectEsc isDigit (shows (ord c))
showLitChar '\ DEL' = showString "\ DEL"
showLitChar '\\' = showString "\\"
showLitChar c | c >= ', ' = showChar c
showLitChar '\a' = showString '\a'
showLitChar '\b' = showString '\b'
showLitChar '\f' = showString '\f'
showLitChar '\n' = showString '\n'
showLitChar '\r' = showString '\r'
showLitChar '\t' = showString '\t'
showLitChar '\v' = showString '\v'
showLitChar '\SO' = protectEsc (== 'H') (showString '\SO')
showLitChar c = showString ('\': asciiTab!c)

protectEsc p f = f . cont
   where cont s@(c:_) | p c = "\&" ++ s
          cont s = s

asciiTab = listArray ('\ NUL', ' ')
  ["NUL", "SOH", "STX", "ETX", "EOT", "ENQ", "ACK", "BEL",
   "BS", "HT", "LF", "VT", "FF", "CR", "SO", "SI",
   "DLE", "DC1", "DC2", "DC3", "DC4", "NAK", "SYN", "ETB",
   "SP"]

lexLitChar :: ReadS String
lexLitChar ('\": s) = [(('\": esc, t) | (esc, t) <- lexEsc s]
   where
   lexEsc (c:s) | c elem 'abfnrtv\"\''' = [[(c), s]]
     lexEsc s@(d:_) | isDigit d = lexDigits s
     lexEsc ('\':'c:s) | c >= '0' && c <= '_-' = [(["", c], s)]
     -- Very crude approximation to \XYZ. Let readers work this out.
     lexEsc s@(c:_) | isUpper c = [span isCharName s]
     lexEsc _ = []
     isCharName c = isUpper c || isDigit c

lexLitChar (c:s) = [[(c), s]]
lexLitChar "" = []
10 Monad Utilities

module Monad (
    MonadPlus(mzero, mplus),
    join, guard, when, unless, ap,
    msum,
    filterM, mapAndUnzipM, zipWithM, zipWithM_, foldM,
    liftM, liftM2, liftM3, liftM4, liftM5,
    -- ...and what the Prelude exports
    Monad(>>=), (>>), return, fail),
    Functor(fmap),
    mapM, mapM_, sequence, sequence_, (<=<),
) where

class Monad m => MonadPlus m where
    mzero :: m a
    mplus :: m a \rightarrow m a \rightarrow m a
    join :: Monad m \Rightarrow m (m a) \rightarrow m a
    guard :: MonadPlus m \Rightarrow Bool \rightarrow m ()
    when :: Monad m \Rightarrow Bool \rightarrow m () \rightarrow m ()
    unless :: Monad m \Rightarrow Bool \rightarrow m () \rightarrow m ()
    ap :: Monad m \Rightarrow m (a \rightarrow b) \rightarrow m a \rightarrow m b
    mapAndUnzipM :: Monad m \Rightarrow (a \rightarrow m (b, c)) \rightarrow [a] \rightarrow m ([b], [c])
    zipWithM :: Monad m \Rightarrow (a \rightarrow b \rightarrow m c) \rightarrow [a] \rightarrow [b] \rightarrow m c
    zipWithM_ :: Monad m \Rightarrow (a \rightarrow b \rightarrow m c) \rightarrow [a] \rightarrow [b] \rightarrow m c
    foldM :: Monad m \Rightarrow (a \rightarrow b \rightarrow m a) \rightarrow a \rightarrow [b] \rightarrow m a
    filterM :: Monad m \Rightarrow (a \rightarrow m Bool) \rightarrow [a] \rightarrow m [a]
    msum :: MonadPlus m \Rightarrow [m a] \rightarrow m a
    liftM :: Monad m \Rightarrow (a \rightarrow b) \rightarrow (m a \rightarrow m b)
    liftM2 :: Monad m \Rightarrow (a \rightarrow b \rightarrow c) \rightarrow (m a \rightarrow m b \rightarrow m c)
    liftM3 :: Monad m \Rightarrow (a \rightarrow b \rightarrow c \rightarrow d) \rightarrow
        (m a \rightarrow m b \rightarrow m c \rightarrow m d)
    liftM4 :: Monad m \Rightarrow (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e) \rightarrow
        (m a \rightarrow m b \rightarrow m c \rightarrow m d \rightarrow m e)
    liftM5 :: Monad m \Rightarrow (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow f) \rightarrow
        (m a \rightarrow m b \rightarrow m c \rightarrow m d \rightarrow m e \rightarrow m f)

The Monad library defines the MonadPlus class, and provides some useful operations on monads.
10.1 Naming conventions

The functions in this library use the following naming conventions:

- A postfix "M" always stands for a function in the Kleisli category: m is added to function results (modulo currying) and nowhere else. So, for example,
  \[ \text{filter} :: (a \rightarrow \text{Bool}) \rightarrow [a] \rightarrow [a] \]
  \[ \text{filterM :: (Monad m) \Rightarrow (a \rightarrow m \text{Bool}) \rightarrow [a] \rightarrow m [a]} \]

- A postfix "_" changes the result type from \( (\text{m} \ a) \) to \( (\text{m} \ () ) \). Thus (in the Prelude):
  \[ \text{sequence} :: \text{Monad m} \Rightarrow [m \ a] \rightarrow m [a] \]
  \[ \text{sequence}_- :: \text{Monad m} \Rightarrow [m \ a] \rightarrow m () \]

- A prefix "m" generalises an existing function to a monadic form. Thus, for example:
  \[ \text{sum} :: \text{Num a} \Rightarrow [a] \rightarrow a \]
  \[ \text{msum :: MonadPlus m} \Rightarrow [m a] \rightarrow m a \]

10.2 Class MonadPlus

The MonadPlus class is defined as follows:

\[ \text{class (Monad m) \Rightarrow MonadPlus m where} \]
  \[ \text{mzero :: m a} \]
  \[ \text{mplus :: m a \rightarrow m a \rightarrow m a} \]

The class methods mzero and mplus are the zero and plus of the monad.

Lists and the Maybe type are instances of MonadPlus, thus:

\[ \text{instance MonadPlus Maybe where} \]
  \[ \text{mzero} = \text{Nothing} \]
  \[ \text{Nothing \ 'mplus' \ ys} = \text{ys} \]
  \[ \text{xs \ 'mplus' \ ys} = \text{xs} \]

\[ \text{instance MonadPlus [] where} \]
  \[ \text{mzero} = [] \]
  \[ \text{mplus} = (+\!\!\!+) \]

10.3 Functions

The join function is the conventional monad join operator. It is used to remove one level of monadic structure, projecting its bound argument into the outer level.
The `mapAndUnzipM` function maps its first argument over a list, returning the result as a pair of lists. This function is mainly used with complicated data structures or a state-transforming monad.

The `zipWithM` function generalises `zipWith` to arbitrary monads. For instance the following function displays a file, prefixing each line with its line number,

```haskell
listFile :: String -> IO ()
listFile nm =
  do cts <- openFile nm
     zipWithM_ (\i line -> do putStrLn (show i); putStrLn "": ""); putStrLn line)
             [1..]
     (lines cts)
```

The `foldM` function is analogous to `fold1`, except that its result is encapsulated in a monad. Note that `foldM` works from left-to-right over the list arguments. This could be an issue where `(>>)` and the "folded function" are not commutative.

```haskell
foldM f a1 [x1, x2, ..., xm ]
==
  do
    a2 <- f a1 x1
    a3 <- f a2 x2
    ...
    f am xm
```

If right-to-left evaluation is required, the input list should be reversed.

The `when` and `unless` functions provide conditional execution of monadic expressions. For example,

```haskell
  when debug (putStrLn "Debugging\n")
```

will output the string "Debugging\n" if the Boolean value `debug` is `True`, and otherwise do nothing.

The monadic lifting operators promote a function to a monad. The function arguments are scanned left to right. For example,

```haskell
liftM2 (+) [0,1] [0,2] = [0,2,1,3]
liftM2 (+) (Just 1) Nothing = Nothing
```

In many situations, the `liftM` operations can be replaced by uses of `ap`, which promotes function application.

```haskell
  return f 'ap' x1 'ap' ... 'ap' xn
```

is equivalent to

```haskell
  liftMn f x1 x2 ... xn
```
10.4 Library Monad

module Monad (
    MonadPlus(mzero, mplus),
    join, guard, when, unless, ap,
    msum,
    filterM, mapAndUnzipM, zipWithM, zipWithM_, foldM,
    liftM, liftM2, liftM3, liftM4, liftM5,
    -- ...and what the Prelude exports
    Monad((>>,>), (>>,), return, fail),
    Functor(fmap),
    mapM, mapM_, sequence, sequence_, (<<),
) where

-- The MonadPlus class definition
class (Monad m) => MonadPlus m where
    mzero :: m a
    mplus :: m a -> m a -> m a

-- Instances of MonadPlus
instance MonadPlus Maybe where
    mzero = Nothing
    Nothing 'mplus' ys = ys
    xs 'mplus' ys = xs

instance MonadPlus [] where
    mzero = []
    mplus = (++)

-- Functions
msum :: MonadPlus m => [m a] -> m a
msum xs = foldr mplus mzero xs

join :: (Monad m) => m (m a) -> m a
join x = x >>= id

when :: (Monad m) => Bool -> m () -> m ()
when p s = if p then s else return ()

unless :: (Monad m) => Bool -> m () -> m ()
unless p s = when (not p) s

ap :: (Monad m) => m (a -> b) -> m a -> m b
ap = liftM2 ($)
10.4 Library Monad

\textbf{guard} :: MonadPlus m \Rightarrow \text{Bool} \rightarrow m ()
\textbf{guard} p = if p then return () else mzero

\textbf{mapAndUnzipM} :: (Monad m) => (a \rightarrow m (b,c)) \rightarrow [a] \rightarrow m ([b], [c])
\textbf{mapAndUnzipM} f xs = sequence (map f xs) >>= return . unzip

\textbf{zipWithM} :: (Monad m) \Rightarrow (a \rightarrow b \rightarrow m c) \rightarrow [a] \rightarrow [b] \rightarrow m [c]
\textbf{zipWithM} f xs ys = sequence (zipWith f xs ys)

\textbf{zipWithM_} :: (Monad m) \Rightarrow (a \rightarrow b \rightarrow m c) \rightarrow [a] \rightarrow [b] \rightarrow m ()
\textbf{zipWithM_} f xs ys = sequence_ (zipWith f xs ys)

\textbf{foldM} :: (Monad m) \Rightarrow (a \rightarrow b \rightarrow m a) \rightarrow a \rightarrow [b] \rightarrow m a
\textbf{foldM} f a [] = return a
\textbf{foldM} f a (x:xs) = f a x >>= \ y \rightarrow \text{foldM} f y xs

\textbf{filterM} :: Monad m \Rightarrow (a \rightarrow m \text{Bool}) \rightarrow [a] \rightarrow m [a]
\textbf{filterM} p [] = return []
\textbf{filterM} p (x:xs) = do { b <- p x;
ys <- filterM p xs;
return (if b then (x:ys) else ys)
}

\textbf{liftM} :: (Monad m) \Rightarrow (a \rightarrow b) \rightarrow (m a \rightarrow m b)
\textbf{liftM} f = \lambda a \rightarrow do { a' <- a; return (f a') }

\textbf{liftM2} :: (Monad m) \Rightarrow (a \rightarrow b \rightarrow c) \rightarrow (m a \rightarrow m b \rightarrow m c)
\textbf{liftM2} f = \lambda a b \rightarrow do { a' <- a; b' <- b; return (f a' b') }

\textbf{liftM3} :: (Monad m) \Rightarrow (a \rightarrow b \rightarrow c \rightarrow d) \rightarrow
(m a \rightarrow m b \rightarrow m c \rightarrow m d)
\textbf{liftM3} f = \lambda a b c \rightarrow do { a' <- a; b' <- b; c' <- c;
return (f a' b' c') }

\textbf{liftM4} :: (Monad m) \Rightarrow (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e) \rightarrow
(m a \rightarrow m b \rightarrow m c \rightarrow m d \rightarrow m e)
\textbf{liftM4} f = \lambda a b c d \rightarrow do { a' <- a; b' <- b; c' <- c; d' <- d;
return (f a' b' c' d') }

\textbf{liftM5} :: (Monad m) \Rightarrow (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow f) \rightarrow
(m a \rightarrow m b \rightarrow m c \rightarrow m d \rightarrow m e \rightarrow m f)
\textbf{liftM5} f = \lambda a b c d e \rightarrow do { a' <- a; b' <- b; c' <- c; d' <- d;
e' <- e; return (f a' b' c' d' e') }
11 Input/Output

module IO (Handle, HandlePosn, IOMode(ReadMode, WriteMode, AppendMode, ReadWriteMode), BufferMode(NoBuffering, LineBuffering, BlockBuffering), SeekMode(AbsoluteSeek, RelativeSeek, SeekFromEnd), stdin, stdout, stderr, openFile, hClose, hFileSize, hIsEOF, isEOF, hSetBuffering, hGetBuffering, hFlush, hGetPosn, hSetPosn, hSeek, hWaitForInput, hReady, hGetChar, hGetLine, hLookAhead, hGetContents, hPutChar, hPutStr, hPutStrLn, hPrint, hIsOpen, hIsClosed, hIsReadable, hIsWritable, hIsSeekable, isAlreadyExistsError, isDoesNotExistError, isAlreadyInUseError, isFullError, isEOFError, isIllegalOperation, isPermissionError, isUserError, ioeGetErrString, ioeGetHandle, ioeGetFileName, try, bracket, bracket_

-- ...and what the Prelude exports
IO, FilePath, IOError, ioError, userError, catch, interact, putChar, putStr, putStrLn, print, getChar, getLine, getContents, readFile, writeFile, appendFile, readIO, readLn ) where

import Ix(Ix)

data Handle = ... -- implementation-dependent
instance Eq Handle where ...
instance Show Handle where .. -- implementation-dependent

data HandlePosn = ... -- implementation-dependent
instance Eq HandlePosn where ...
instance Show HandlePosn where --- -- implementation-dependent

data IOMode = ReadMode | WriteMode | AppendMode | ReadWriteMode
  deriving (Eq, Ord, Ix, Bounded, Enum, Read, Show)
data BufferMode = NoBuffering | LineBuffering
  | BlockBuffering (Maybe Int)
  deriving (Eq, Ord, Read, Show)
data SeekMode = AbsoluteSeek | RelativeSeek | SeekFromEnd
  deriving (Eq, Ord, Ix, Bounded, Enum, Read, Show)

stdin, stdout, stderr :: Handle

openFile :: FilePath -> IOMode -> IO Handle
hClose :: Handle -> IO ()
<table>
<thead>
<tr>
<th>Function</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>hFileSize</td>
<td>Handle -&gt; IO Integer</td>
</tr>
<tr>
<td>hIsEOF</td>
<td>Handle -&gt; IO Bool</td>
</tr>
<tr>
<td>isEOF</td>
<td>IO Bool</td>
</tr>
<tr>
<td>isEOF</td>
<td>= hIsEOF stdin</td>
</tr>
<tr>
<td>hSetBuffering</td>
<td>Handle -&gt; BufferMode -&gt; IO ()</td>
</tr>
<tr>
<td>hGetBuffering</td>
<td>Handle -&gt; IO BufferMode</td>
</tr>
<tr>
<td>hFlush</td>
<td>Handle -&gt; IO ()</td>
</tr>
<tr>
<td>hGetPosn</td>
<td>Handle -&gt; IO HandlePosn</td>
</tr>
<tr>
<td>hSetPosn</td>
<td>HandlePosn -&gt; IO ()</td>
</tr>
<tr>
<td>hSeek</td>
<td>Handle -&gt; SeekMode -&gt; Integer -&gt; IO ()</td>
</tr>
<tr>
<td>hWaitForInput</td>
<td>Handle -&gt; Int -&gt; IO Bool</td>
</tr>
<tr>
<td>hReady</td>
<td>Handle -&gt; IO Bool</td>
</tr>
<tr>
<td>hReady h</td>
<td>= hWaitForInput h 0</td>
</tr>
<tr>
<td>hGetChar</td>
<td>Handle -&gt; IO Char</td>
</tr>
<tr>
<td>hGetLine</td>
<td>Handle -&gt; IO String</td>
</tr>
<tr>
<td>hLookAhead</td>
<td>Handle -&gt; IO Char</td>
</tr>
<tr>
<td>hGetContents</td>
<td>Handle -&gt; IO String</td>
</tr>
<tr>
<td>hPutChar</td>
<td>Handle -&gt; Char -&gt; IO ()</td>
</tr>
<tr>
<td>hPutStr</td>
<td>Handle -&gt; String -&gt; IO ()</td>
</tr>
<tr>
<td>hPutStrLn</td>
<td>Handle -&gt; String -&gt; IO ()</td>
</tr>
<tr>
<td>hPrint</td>
<td>Show a =&gt; Handle -&gt; a -&gt; IO ()</td>
</tr>
<tr>
<td>hIsOpen</td>
<td>Handle -&gt; IO Bool</td>
</tr>
<tr>
<td>hIsClosed</td>
<td>Handle -&gt; IO Bool</td>
</tr>
<tr>
<td>hIsReadable</td>
<td>Handle -&gt; IO Bool</td>
</tr>
<tr>
<td>hIsWritable</td>
<td>Handle -&gt; IO Bool</td>
</tr>
<tr>
<td>hIsSeekable</td>
<td>Handle -&gt; IO Bool</td>
</tr>
<tr>
<td>isAlreadyExistsError</td>
<td>IOError -&gt; Bool</td>
</tr>
<tr>
<td>isDoesNotExistError</td>
<td>IOError -&gt; Bool</td>
</tr>
<tr>
<td>isAlreadyInUseError</td>
<td>IOError -&gt; Bool</td>
</tr>
<tr>
<td>isFullError</td>
<td>IOError -&gt; Bool</td>
</tr>
<tr>
<td>isEOFError</td>
<td>IOError -&gt; Bool</td>
</tr>
<tr>
<td>isIllegalOperation</td>
<td>IOError -&gt; Bool</td>
</tr>
<tr>
<td>isPermissionError</td>
<td>IOError -&gt; Bool</td>
</tr>
<tr>
<td>isUserError</td>
<td>IOError -&gt; Bool</td>
</tr>
<tr>
<td>ioeGetErrorString</td>
<td>IOError -&gt; String</td>
</tr>
<tr>
<td>ioeGetHandle</td>
<td>IOError -&gt; Maybe Handle</td>
</tr>
<tr>
<td>ioeGetFileName</td>
<td>IOError -&gt; Maybe FilePath</td>
</tr>
<tr>
<td>try</td>
<td>IO a -&gt; Either IOError a</td>
</tr>
<tr>
<td>bracket</td>
<td>IO a -&gt; (a -&gt; IO b) -&gt; (a -&gt; IO c) -&gt; IO c</td>
</tr>
<tr>
<td>bracket_</td>
<td>IO a -&gt; (a -&gt; IO b) -&gt; IO c -&gt; IO c</td>
</tr>
</tbody>
</table>
11.1 I/O Errors

The monadic I/O system used in Haskell is described by the Haskell language report. Commonly used I/O functions such as print are part of the standard prelude and need not be explicitly imported. This library contains more advanced I/O features. Some related operations on file systems are contained in the Directory library.

11.1 I/O Errors

Errors of type IOError are used by the I/O monad. This is an abstract type; the library provides functions to interrogate and construct values in IOError:

- isAlreadyExistsError – the operation failed because one of its arguments already exists.
- isDoesNotExistError – the operation failed because one of its arguments does not exist.
- isAlreadyInUseError – the operation failed because one of its arguments is a single-use resource, which is already being used (for example, opening the same file twice for writing might give this error).
- isFullError – the operation failed because the device is full.
- isEOFError – the operation failed because the end of file has been reached.
- isIllegalOperation – the operation is not possible.
- isPermissionError – the operation failed because the user does not have sufficient operating system privilege to perform that operation.
- isUserError – a programmer-defined error value has been raised using fail.

All these functions return a Bool, which is True if its argument is the corresponding kind of error, and False otherwise.

Any computation which returns an IO result may fail with isIllegalOperationError. Additional errors which could be raised by an implementation are listed after the corresponding operation. In some cases, an implementation will not be able to distinguish between the possible error causes. In this case it should return isIllegalOperationError.

Three additional functions are provided to obtain information about an error value. These are ioeGetHandle which returns Just hdl if the error value refers to handle hdl and Nothing otherwise; ioeGetFileName which returns Just name if the error value refers to file name, and Nothing otherwise; and ioeGetErrorString which returns a string. For "user" errors (those which are raised using fail), the string returned by ioeGetErrorString is the argument that was passed to fail; for all other errors, the string is implementation-dependent.

The try function returns an error in a computation explicitly using the Either type.
The bracket function captures a common allocate, compute, deallocate idiom in which the deallocation step must occur even in the case of an error during computation. This is similar to try-catch-finally in Java.

module IO where

-- Just provide an implementation of the system-indentent
-- actions that IO exports.
try :: IO a -> IO (Either IOError a)
try f = catch (do r <- f
        return (Right r))
      (return . Left)

bracket :: IO a -> (a -> IO b) -> (a -> IO c) -> IO c
bracket before after m = do
  x <- before
  rs <- try (m x)
  after x
  case rs of
    Right r -> return r
    Left e -> ioError e

-- variant of the above where middle computation doesn’t want x
bracket_ :: IO a -> (a -> IO b) -> IO c -> IO c
bracket_ before after m = do
  x <- before
  rs <- try m
  after x
  case rs of
    Right r -> return r
    Left e -> ioError e

11.2 Files and Handles

Haskell interfaces to the external world through an abstract file system. This file system is a collection of named file system objects, which may be organised in directories (see Directory). In some implementations, directories may themselves be file system objects and could be entries in other directories. For simplicity, any non-directory file system object is termed a file, although it could in fact be a communication channel, or any other object recognised by the operating system. Physical files are persistent, ordered files, and normally reside on disk.

File and directory names are values of type String, whose precise meaning is operating system dependent. Files can be opened, yielding a handle which can then be used to operate on the contents of that file.
Haskell defines operations to read and write characters from and to files, represented by values of type `Handle`. Each value of this type is a `handle`: a record used by the Haskell run-time system to manage I/O with file system objects. A handle has at least the following properties:

- whether it manages input or output or both;
- whether it is `open`, `closed` or `semi-closed`;
- whether the object is seekable;
- whether buffering is disabled, or enabled on a line or block basis;
- a buffer (whose length may be zero).

Most handles will also have a current I/O position indicating where the next input or output operation will occur. A handle is `readable` if it manages only input or both input and output; likewise, it is `writable` if it manages only output or both input and output. A handle is `open` when first allocated. Once it is closed it can no longer be used for either input or output, though an implementation cannot re-use its storage while references remain to it. Handles are in the `Show` and `Eq` classes. The string produced by showing a handle is system dependent; it should include enough information to identify the handle for debugging. A handle is equal according to `==` only to itself; no attempt is made to compare the internal state of different handles for equality.

### 11.2.1 Semi-Closed Handles

The operation `hGetContents` puts a handle `hdl` into an intermediate state, `semi-closed`. In this state, `hdl` is effectively closed, but items are read from `hdl` on demand and accumulated in a special stream returned by `hGetContents hdl`.

Any operation except for `hClose` that fails because a handle is closed, also fails if a handle is semi-closed. A semi-closed handle becomes closed:

- if `hClose` is applied to it;
- if an I/O error occurs when reading an item from the file item from the stream;
- or once the entire contents of the file has been read.

Once a semi-closed handle becomes closed, the contents of the associated stream becomes fixed, and is the list of those items which were successfully read from that handle. Any I/O errors encountered while a handle is semi-closed are simply discarded.
11.2.2 Standard Handles

Three handles are allocated during program initialisation. The first two (stdin and stdout) manage input or output from the Haskell program's standard input or output channel respectively. The third (stderr) manages output to the standard error channel. These handles are initially open.

11.3 Opening and Closing Files

11.3.1 Opening Files

Computation openFile file mode allocates and returns a new, open handle to manage the file file. It manages input if mode is ReadMode, output if mode is WriteMode or AppendMode, and both input and output if mode is ReadWriteMode.

If the file does not exist and it is opened for output, it should be created as a new file. If mode is WriteMode and the file already exists, then it should be truncated to zero length. Some operating systems delete empty files, so there is no guarantee that the file will exist following an openFile with mode WriteMode unless it is subsequently written to successfully. The handle is positioned at the end of the file if mode is AppendMode, and otherwise at the beginning (in which case its internal I/O position is 0). The initial buffer mode is implementation-dependent.

If openFile fails on a file opened for output, the file may still have been created if it did not already exist.

Implementations should enforce as far as possible, locally to the Haskell process, multiple-reader single-writer locking on files. Thus there may either be many handles on the same file which manage input, or just one handle on the file which manages output. If any open or semi-closed handle is managing a file for output, no new handle can be allocated for that file. If any open or semi-closed handle is managing a file for input, new handles can only be allocated if they do not manage output. Whether two files are the same is implementation-dependent, but they should normally be the same if they have the same absolute path name and neither has been renamed, for example.

Error reporting: the openFile computation may fail with isNewlyInUseError if the file is already open and cannot be reopened; isDoesNotExistError if the file does not exist; or isPermissionError if the user does not have permission to open the file.

11.3.2 Closing Files

Computation hClose hdl makes handle hdl closed. Before the computation finishes, if hdl is writable its buffer is flushed as for hFlush. If the operation fails for any reason, any further operations on the handle will still fail as if hdl had been successfully closed.
11.4 Determining the Size of a File

For a handle \( hdl \) which is attached to a physical file, \( \text{hFileSize} \ hdl \) returns the size of that file in 8-bit bytes \( (\geq 0) \).

11.4.1 Detecting the End of Input

For a readable handle \( hdl \), computation \( \text{hIsEOF} \ hdl \) returns True if no further input can be taken from \( hdl \); for a handle attached to a physical file this means that the current I/O position is equal to the length of the file. Otherwise, it returns False. The computation \( \text{isEOF} \) is identical, except that it works only on stdin.

11.4.2 Buffering Operations

Three kinds of buffering are supported: line-buffering, block-buffering or no-buffering. These modes have the following effects. For output, items are written out from the internal buffer according to the buffer mode:

- **line-buffering**: the entire buffer is written out whenever a newline is output, the buffer overflows, a flush is issued, or the handle is closed.

- **block-buffering**: the entire buffer is written out whenever it overflows, a flush is issued, or the handle is closed.

- **no-buffering**: output is written immediately, and never stored in the buffer.

The buffer is emptied as soon as it has been written out.

Similarly, input occurs according to the buffer mode for handle \( hdl \).

- **line-buffering**: when the buffer for \( hdl \) is not empty, the next item is obtained from the buffer; otherwise, when the buffer is empty, characters are read into the buffer until the next newline character is encountered or the buffer is full. No characters are available until the newline character is available or the buffer is full.

- **block-buffering**: when the buffer for \( hdl \) becomes empty, the next block of data is read into the buffer.

- **no-buffering**: the next input item is read and returned.

For most implementations, physical files will normally be block-buffered and terminals will normally be line-buffered.

Computation \( \text{hSetBuffering} \ hdl \ mode \) sets the mode of buffering for handle \( hdl \) on subsequent reads and writes.
• If \textit{mode} is \texttt{LineBuffering}, line-buffering is enabled if possible.

• If \textit{mode} is \texttt{BlockBuffering size}, then block-buffering is enabled if possible. The size of the buffer is \texttt{n} items if \texttt{size} is \texttt{Just n} and is otherwise implementation-dependent.

• If \textit{mode} is \texttt{NoBuffering}, then buffering is disabled if possible.

If the buffer mode is changed from \texttt{BlockBuffering} or \texttt{LineBuffering} to \texttt{NoBuffering}, then

• if \texttt{hdl} is writable, the buffer is flushed as for \texttt{hFlush};

• if \texttt{hdl} is not writable, the contents of the buffer is discarded.

\textit{Error reporting}: the \texttt{hSetBuffering} computation may fail with \texttt{isPermissionError} if the handle has already been used for reading or writing and the implementation does not allow the buffering mode to be changed.

Computation \texttt{hGetBuffering hdl} returns the current buffering mode for \texttt{hdl}.

The default buffering mode when a handle is opened is implementation-dependent and may depend on the file system object which is attached to that handle.

\subsection{11.4.3 Flushing Buffers}

Computation \texttt{hFlush hdl} causes any items buffered for output in handle \texttt{hdl} to be sent immediately to the operating system.

\textit{Error reporting}: the \texttt{hFlush} computation may fail with: \texttt{isFullError} if the device is full; \texttt{isPermissionError} if a system resource limit would be exceeded. It is unspecified whether the characters in the buffer are discarded or retained under these circumstances.

\section{11.5 Repositioning Handles}

\subsection{11.5.1 Revisiting an I/O Position}

Computation \texttt{hGetPosn hdl} returns the current I/O position of \texttt{hdl} as a value of the abstract type \texttt{HandlePosn}. If a call to \texttt{hGetPosn h} returns a position \texttt{p}, then computation \texttt{hSetPosn p} sets the position of \texttt{h} to the position it held at the time of the call to \texttt{hGetPosn}.

\textit{Error reporting}: the \texttt{hSetPosn} computation may fail with: \texttt{isPermissionError} if a system resource limit would be exceeded.

\subsection{11.5.2 Seeking to a new Position}

Computation \texttt{hSeek hdl mode i} sets the position of handle \texttt{hdl} depending on \texttt{mode}. If \texttt{mode} is:
• `AbsoluteSeek`: the position of `hdl` is set to `i`.

• `RelativeSeek`: the position of `hdl` is set to offset `i` from the current position.

• `SeekFromEnd`: the position of `hdl` is set to offset `i` from the end of the file.

The offset is given in terms of 8-bit bytes.

If `hdl` is block- or line-buffered, then seeking to a position which is not in the current buffer will first cause any items in the output buffer to be written to the device, and then cause the input buffer to be discarded. Some handles may not be seekable (see `hIsSeekable`), or only support a subset of the possible positioning operations (for instance, it may only be possible to seek to the end of a tape, or to a positive offset from the beginning or current position). It is not possible to set a negative I/O position, or for a physical file, an I/O position beyond the current end-of-file.

*Error reporting*: the `hSeek` computation may fail with: `isPermissionError` if a system resource limit would be exceeded.

### 11.6 Handle Properties

The functions `hIsOpen`, `hIsClosed`, `hIsReadable`, `hIsWritable` and `hIsSeekable` return information about the properties of a handle. Each of these returns `True` if the handle has the specified property, and `False` otherwise.

### 11.7 Text Input and Output

Here we define a standard set of input operations for reading characters and strings from text files, using handles. Many of these functions are generalizations of Prelude functions. I/O in the Prelude generally uses `stdin` and `stdout`; here, handles are explicitly specified by the I/O operation.

#### 11.7.1 Checking for Input

Computation `hWaitForInput hdl t` waits until input is available on handle `hdl`. It returns `True` as soon as input is available on `hdl`, or `False` if no input is available within `t` milliseconds.

Computation `hReady hdl` indicates whether at least one item is available for input from handle `hdl`.

Computation `hGetChar hdl` reads a character from the file or channel managed by `hdl`.

Computation `hGetLine hdl` reads a line from the file or channel managed by `hdl`, similar to `getLine` in the Prelude.
Error reporting: the hWaitForInput, hReady and hGetChar computations may fail with: isE0FError if the end of file has been reached.

11.7.2 Reading Ahead

Computation hLookAhead hdl returns the next character from handle hdl without removing it from the input buffer, blocking until a character is available.

Error reporting: the hLookAhead computation may fail with: isE0FError if the end of file has been reached.

Computation hGetContents hdl returns the list of characters corresponding to the unread portion of the channel or file managed by hdl, which is made semi-closed.

Error reporting: the hGetContents computation may fail with: isE0FError if the end of file has been reached.

Computation hPutChar hdl c writes the character c to the file or channel managed by hdl. Characters may be buffered if buffering is enabled for hdl.

Computation hPutStr hdl s writes the string s to the file or channel managed by hdl.

Computation hPrint hdl t writes the string representation of t given by the shows function to the file or channel managed by hdl and appends a newline.

Error reporting: the hPutChar, hPutStr and hPrint computations may fail with: isFull-Error if the device is full; or isPermissionError if another system resource limit would be exceeded.

11.8 Examples

Here are some simple examples to illustrate Haskell I/O.

11.8.1 Summing Two Numbers

This program reads and sums two Integers.
import IO

main = do
  hSetBuffering stdout NoBuffering
  putStrLn "Enter an integer: "
  x1 <- readNum
  putStrLn "Enter another integer: "
  x2 <- readNum
  putStrLn ("Their sum is " ++ show (x1+x2) ++ "\n")
where readNum :: IO Integer
  readNum = do { line <- getLine; readIO line }

11.8.2 Copying Files

A simple program to create a copy of a file, with all lower-case characters translated to upper-case. This program will not allow a file to be copied to itself. This version uses character-level I/O. Note that exactly two arguments must be supplied to the program.

import IO
import System

main = do
  [f1,f2] <- getArgs
  h1 <- openFile f1 ReadMode
  h2 <- openFile f2 WriteMode
  copyFile h1 h2
  hClose h1
  hClose h2

  copyFile h1 h2 = do
    eof <- hIsEOF h1
    if eof then return () else
      do
        c <- hGetChar h1
        hPutChar h2 (toUpper c)
        copyFile h1 h2

An equivalent but much shorter version, using string I/O is:

import System

main = do
  [f1,f2] <- getArgs
  s <- readFile f1
  writeFile f2 (map toUpper s)
12 Directory Functions

module Directory (  
  Permissions, 
  readable, writable, executable, searchable, 
  createDirectory, removeDirectory, removeFile, 
  renameDirectory, renameFile, getDirectoryContents, 
  getCurrentDirectory, setCurrentDirectory, 
  doesFileExist, doesDirectoryExist, 
  getPermissions, setPermissions, 
  getModificationTime ) where

import Time ( ClockTime )

data Permissions = ... -- Abstract

instance Eq Permissions where ...
instance Ord Permissions where ...
instance Read Permissions where ...
instance Show Permissions where ...

readable, writable, executable, searchable :: Permissions -> Bool

createDirectory :: FilePath -> IO ()
removeDirectory :: FilePath -> IO ()
removeFile :: FilePath -> IO ()
renameDirectory :: FilePath -> FilePath -> IO ()
renameFile :: FilePath -> FilePath -> IO ()

getDirectoryContents :: FilePath -> IO [FilePath]
getCurrentDirectory :: IO FilePath
setCurrentDirectory :: FilePath -> IO ()

doesFileExist :: FilePath -> IO Bool
doesDirectoryExist :: FilePath -> IO Bool

getPermissions :: FilePath -> IO Permissions
setPermissions :: FilePath -> Permissions -> IO ()

getModificationTime :: FilePath -> IO ClockTime

These functions operate on directories in the file system.

Any Directory operation could raise an isIllegalOperationError, as described in Section 11.1; all other permissible errors are described below. Note that, in particular, if an implementation does not support an operation it should raise an isIllegalOperationError.
A directory contains a series of entries, each of which is a named reference to a file system object (file, directory etc.). Some entries may be hidden, inaccessible, or have some administrative function (for instance, "." or "." under POSIX), but all such entries are considered to form part of the directory contents. Entries in sub-directories are not, however, considered to form part of the directory contents. Although there may be file system objects other than files and directories, this library does not distinguish between physical files and other non-directory objects. All such objects should therefore be treated as if they are files.

Each file system object is referenced by a path. There is normally at least one absolute path to each file system object. In some operating systems, it may also be possible to have paths which are relative to the current directory.

Computation createDirectory dir creates a new directory dir which is initially empty, or as near to empty as the operating system allows.

Error reporting: the createDirectory computation may fail with: isPermissionError if the user is not permitted to create the directory; isAlreadyExistsError if the directory already exists.

Computation removeDirectory dir removes an existing directory dir. The implementation may specify additional constraints which must be satisfied before a directory can be removed (for instance, the directory has to be empty, or may not be in use by other processes). It is not legal for an implementation to partially remove a directory unless the entire directory is removed. A conformant implementation need not support directory removal in all situations (for instance, removal of the root directory).

Computation removeFile file removes the directory entry for an existing file file, where file is not itself a directory. The implementation may specify additional constraints which must be satisfied before a file can be removed (for instance, the file may not be in use by other processes).

Error reporting: the removeDirectory and removeFile computations may fail with: isPermissionError if the user is not permitted to remove the file/directory; or isDoesNotExistError if the file/directory does not exist.

Computation renameDirectory old new changes the name of an existing directory from old to new. If the new directory already exists, it is atomically replaced by the old directory. If the new directory is neither the old directory nor an alias of the old directory, it is removed as if by removeDirectory. A conformant implementation need not support renaming directories in all situations (for instance, renaming to an existing directory, or across different physical devices), but the constraints must be documented.

Computation renameFile old new changes the name of an existing file system object from old to new. If the new object already exists, it is atomically replaced by the old object. Neither path may refer to an existing directory. A conformant implementation need not support renaming files in all situations (for instance, renaming across different physical devices), but the constraints must be documented.
Error reporting: the renameDirectory and renameFile computations may fail with: isPermissionError if the user is not permitted to rename the file/directory, or if either argument to renameFile is a directory; or isDoesNotExistError if the file/directory does not exist.

Computation getDirectoryContents dir returns a list of all entries in dir.

If the operating system has a notion of current directories, getCurrentDirectory returns an absolute path to the current directory of the calling process.

Error reporting: the getDirectoryContents and getCurrentDirectory computations may fail with: isPermissionError if the user is not permitted to access the directory; or isDoesNotExistError if the directory does not exist.

If the operating system has a notion of current directories, setCurrentDirectory dir changes the current directory of the calling process to dir.

Error reporting: the setCurrentDirectory computation may fail with: isPermissionError if the user is not permitted to change directory to that specified; or isDoesNotExistError if the directory does not exist.

The Permissions type is used to record whether certain operations are permissible on a file/directory. getPermissions and setPermissions get and set these permissions, respectively. Permissions apply both to files and directories. For directories, the executable field will be False, and for files the searchable field will be False. Note that directories may be searchable without being readable, if permission has been given to use them as part of a path, but not to examine the directory contents.

Note that to change some, but not all permissions, a construct on the following lines must be used.

```haskell
makeReadable f = do
    p <- getPermissions f
    setPermissions f (p {readable = True})
```

The operation doesDirectoryExist returns True if the argument file exists and is a directory, and False otherwise. The operation doesFileExist returns True if the argument file exists and is not a directory, and False otherwise.

The getModificationTime operation returns the clock time at which the file/directory was last modified.

Error reporting: the get(set)Permissions, doesFile(Directory)Exist, and getModificationTime computations may fail with: isPermissionError if the user is not permitted to access the appropriate information; or isDoesNotExistError if the file/directory does not exist. The setPermissions computation may also fail with: isPermissionError if the user is not permitted to change the permission for the specified file or directory; or isDoesNotExistError if the file/directory does not exist.
13 System Functions

module System (
    ExitCode(ExitSuccess, ExitFailure),
    getArgs, getProgName, getEnv, system, exitWith, exitFailure
) where

data ExitCode = ExitSuccess | ExitFailure Int
    deriving (Eq, Ord, Read, Show)

getArgs :: IO [String]
getProgName :: IO String
getEnv :: String -> IO String
system :: String -> IO ExitCode
exitWith :: ExitCode -> IO a
exitFailure :: IO a

This library describes the interaction of the program with the operating system.

Any System operation could raise an isIllegalOperationError, as described in Section 11.1; all other permissible errors are described below. Note that, in particular, if an implementation does not support an operation it must raise an isIllegalOperationError.

The ExitCode type defines the exit codes that a program can return. ExitSuccess indicates successful termination; and ExitFailure code indicates program failure with value code. The exact interpretation of code is operating-system dependent. In particular, some values of code may be prohibited (for instance, 0 on a POSIX-compliant system).

Computation getArgs returns a list of the program’s command line arguments (not including the program name). Computation getProgName returns the name of the program as it was invoked. Computation getEnv var returns the value of the environment variable var. If variable var is undefined, the isDoesNotExistError exception is raised.

Computation system cmd returns the exit code produced when the operating system processes the command cmd.

Computation exitWith code terminates the program, returning code to the program’s caller. Before the program terminates, any open or semi-closed handles are first closed. The caller may interpret the return code as it wishes, but the program should return ExitSuccess to mean normal completion, and ExitFailure n to mean that the program encountered a problem from which it could not recover. The value exitFailure is equal to exitWith (ExitFailure exitfail), where exitfail is implementation-dependent. exitWith bypasses the error handling in the I/O monad and cannot be intercepted by catch.

If a program terminates as a result of calling error or because its value is otherwise determined to be ⊥, then it is treated identically to the computation exitFailure. Otherwise, if any program p terminates without calling exitWith explicitly, it is treated identically to
the computation

\[(p >>= \text{exitWith ExitSuccess}) \text{ 'catch' } _\_ \rightarrow \text{exitFailure}\]
14 Dates and Times

module Time (
    ClockTime,
    Month(January,February, March, April, May, June,
        July, August, September, October, November, December),
    Day(Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, Saturday),
    CalendarTime(CalendarTime, ctYear, ctMonth, ctDay, ctHour, ctMin,
        ctPicosec, ctWDay, ctYDay, ctTZName, ctTZ, ctIsDST),
    TimeDiff(TimeDiff, tdYear, tdMonth, tdDay, tdHour,
        tdMin, tdSec, tdPicosec),
    getClockTime, addToClockTime, diffClockTimes,
    toCalendarTime, toUTCTime, toClockTime,
    calendarTimeToString, formatCalendarTime ) where

import Ix(Ix)

data ClockTime = ...  -- Implementation-dependent
instance Ord ClockTime where ... 
instance Eq ClockTime where ...

data Month = January  | February  | March    | April  
            | May      | June     | July   | August
            | September| October  | November| December
    deriving (Eq, Ord, Enum, Bounded, Ix, Read, Show)

data Day = Sunday   | Monday   | Tuesday  | Wednesday| Thursday 
         | Friday   | Saturday
    deriving (Eq, Ord, Enum, Bounded, Ix, Read, Show)

data CalendarTime = CalendarTime {
    ctYear    :: Int, 
    ctMonth   :: Month, 
    ctDay, ctHour, ctMin, ctSec :: Int, 
    ctPicosec :: Integer, 
    ctWDay    :: Day, 
    ctYDay    :: Int, 
    ctTZName  :: String, 
    ctTZ      :: Int, 
    ctIsDST   :: Bool }
    deriving (Eq, Ord, Read, Show)

data TimeDiff = TimeDiff { 
    tdYear, tdMonth, tdDay, tdHour, tdMin, tdSec :: Int, 
    tdPicosec :: Integer }
    deriving (Eq, Ord, Read, Show)
-- Functions on times
getClockTime :: IO ClockTime
addToClockTime :: TimeDiff -> ClockTime -> ClockTime
diffClockTimes :: ClockTime -> ClockTime -> TimeDiff
toCalendarTime :: ClockTime -> IO CalendarTime
toUTCTime :: ClockTime -> CalendarTime
toClockTime :: CalendarTime -> ClockTime
calendarTimeToString :: CalendarTime -> String
formatCalendarTime :: TimeLocale -> String -> CalendarTime -> String

The `Time` library provides standard functionality for clock times, including timezone information. It follows RFC 1129 in its use of Coordinated Universal Time (UTC).

`ClockTime` is an abstract type, used for the system's internal clock time. Clock times may be compared directly or converted to a calendar time `CalendarTime` for I/O or other manipulations. `CalendarTime` is a user-readable and manipulable representation of the internal `ClockTime` type. The numeric fields have the following ranges.

<table>
<thead>
<tr>
<th>Value</th>
<th>Range</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ctYear</td>
<td>-maxInt ... maxInt</td>
<td>Pre-Gregorian dates are inaccurate</td>
</tr>
<tr>
<td>ctDay</td>
<td>1 ... 31</td>
<td></td>
</tr>
<tr>
<td>ctHour</td>
<td>0 ... 23</td>
<td></td>
</tr>
<tr>
<td>ctMin</td>
<td>0 ... 59</td>
<td></td>
</tr>
<tr>
<td>ctSec</td>
<td>0 ... 61</td>
<td>Allows for two Leap Seconds</td>
</tr>
<tr>
<td>ctPicosec</td>
<td>0 ... ((10^{12}) - 1)</td>
<td></td>
</tr>
<tr>
<td>ctYDay</td>
<td>0 ... 365</td>
<td>364 in non-Leap years</td>
</tr>
<tr>
<td>ctTZ</td>
<td>-89999 ... 89999</td>
<td>Variation from UTC in seconds</td>
</tr>
</tbody>
</table>

The `ctTZName` field is the name of the time zone. The `ctIsDST` field is True if Daylight Savings Time would be in effect, and False otherwise. The `TimeDiff` type records the difference between two clock times in a user-readable way.

Function `getClockTime` returns the current time in its internal representation. The expression `addToClockTime \(d \ t\)` adds a time difference \(d\) and a clock time \(t\) to yield a new clock time. The difference \(d\) may be either positive or negative. The expression `diffClockTimes \(t1 \ t2\)` returns the difference between two clock times \(t1\) and \(t2\) as a `TimeDiff`.

Function `toCalendarTime \(t\)` converts \(t\) to a local time, modified by the timezone and daylight savings time settings in force at the time of conversion. Because of this dependence on the local environment, `toCalendarTime` is in the IO monad.

Function `toUTCTime \(t\)` converts \(t\) into a `CalendarTime` in standard UTC format.
toClockTime l converts l into the corresponding internal ClockTime ignoring the contents of the ctWDay, ctYDay, ctTZName, and ctIsDST fields.

Function calendarTimeToString formats calendar times using local conventions and a formatting string.

14.1 Library Time

module Time (  
    ClockTime,  
    Month(January,February,March, April, May, June,  
        July, August, September, October, November, December),  
    Day(Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, Saturday),  
    CalendarTime(CalendarTime, ctYear, ctMonth, ctDay, ctHour, ctMin,  
        ctPicosec, ctWDay, ctYDay, ctTZName, ctTZ, ctIsDST),  
    TimeDiff(TimeDiff, tdYear, tdMonth, tdDay,  
        tdHour, tdMin, tdSec, tdPicosec),  
    getClockTime, addToClockTime, diffClockTimes,  
    toCalendarTime, toUTCTime, toClockTime,  
    calendarTimeToString, formatCalendarTime ) where

import Ix(Ix)
import Locale(TimeLocale(..),defaultTimeLocale)
import Char ( intToDigit )

data ClockTime = ... -- Implementation-dependent
instance Ord ClockTime where ...
instance Eq ClockTime where ...

data Month = January | February | March | April  
| May | June | July | August  
| September | October | November | December
        deriving (Eq, Ord, Enum, Bounded, Ix, Read, Show)

data Day = Sunday | Monday | Tuesday | Wednesday | Thursday  
| Friday | Saturday
        deriving (Eq, Ord, Enum, Bounded, Ix, Read, Show)
data CalendarTime = CalendarTime {
  ctYear : Int,
  ctMonth : Month,
  ctDay, ctHour, ctMin, ctSec : Int,
  ctPicosec : Integer,
  ctWDay : Day,
  ctyDay : Int,
  ctTZName : String,
  ctTZ : Int,
  ctIsDST : Bool
}
  } deriving (Eq, Ord, Read, Show)

data TimeDiff = TimeDiff {
  tdYear, tdMonth, tdDay, tdHour, tdMin, tdSec : Int,
  tdPicosec : Integer
}
  } deriving (Eq, Ord, Read, Show)

gETCHCKTIME :: IO ClockTime
getClockTime = ... -- Implementation-dependent

gETCHCKTIME :: TimeDiff -> ClockTime -> ClockTime
addToClockTime = ... -- Implementation-dependent

diffCLOCKTIME :: ClockTime -> ClockTime -> TimeDiff
diffCLOCKTIMES ct1 ct2 = ... -- Implementation-dependent

toCLOCKTIME :: ClockTime -> IO CalendarTime
toCLOCKTIME ct = ... -- Implementation-dependent

toUTCTIME :: ClockTime -> CalendarTime
toUTCTIME ct = ... -- Implementation-dependent

toCLOCKTIME :: CalendarTime -> ClockTime
toCLOCKTIME cal = ... -- Implementation-dependent

calendarTimeToString :: CalendarTime -> String
calendarTimeToString = formatCalendarTime defaultTimeLocale "%c"
formatCalendarTime :: TimeLocale -> String -> CalendarTime -> String
formatCalendarTime l fmt ct@(CalendarTime year mon day hour min sec sdec
  wday yday tzname _ _) =
  doFmt fmt
where doFmt ("%":c:cs) = decode c ++ doFmt cs
  doFmt (c:cs) = c : doFmt cs
  doFmt "" = ""

  to12 :: Int -> Int
  to12 h = let h' = h `mod` 12 in if h' == 0 then 12 else h'

  decode 'A' = fst (wDays l !: fromEnum wday)
  decode 'a' = snd (wDays l !: fromEnum wday)
  decode 'B' = fst (months l !: fromEnum mon)
  decode 'b' = snd (months l !: fromEnum mon)
  decode 'h' = snd (months l !: fromEnum mon)
  decode 'C' = show2 (year 'quot' 100)
  decode 'c' = doFmt (dateTimeFmt l)
  decode 'D' = doFmt "%m/%d/%y"
  decode 'd' = show2 day
  decode 'e' = show2' day
  decode 'H' = show2 hour
  decode 'I' = show2 (to12 hour)
  decode 'j' = show3 yday
  decode 'k' = show2' hour
  decode 'l' = show2' (to12 hour)
  decode 'M' = show2 min
  decode 'm' = show2 (fromEnum mon+1)
  decode 'n' = "\n"
  decode 'p' = (if hour < 12 then fst else snd) (amPm l)
  decode 'R' = doFmt "%H:%M"
  decode 'r' = doFmt (time12Fmt l)
  decode 'T' = doFmt "%H:%M:%S"
  decode 't' = "\t"
  decode 'S' = show2 sec
  decode 's' = ... -- Implementation-dependent

  decode 'U' = show2 (((yday + 7 - fromEnum wday) 'div' 7))
  decode 'u' = show (let n = fromEnum wday in
    if n == 0 then 7 else n)

  decode 'V' =
    let (week, days) =
      (yday + 7 - if fromEnum wday > 0 then
        fromEnum wday - 1 else 6) 'divMod' 7
    in show2 (if days >= 4 then
week+1
   else if week == 0 then 53 else week)
   decode 'W' =
      show2 ((yday + 7 - if fromEnum wday > 0 then
              fromEnum wday - 1 else 6) 'div' 7)
   decode 'w' = show (fromEnum wday)
   decode 'X' = doFmt (timeFmt 1)
   decode 'x' = doFmt (dateFmt 1)
   decode 'Y' = show year
   decode 'y' = show2 (year 'rem' 100)
   decode 'Z' = tzname
   decode '%' = "%"
   decode c = [c]

show2, show2', show3 :: Int -> String
show2 x = [intToDigit (x 'quot' 10), intToDigit (x 'rem' 10)]
show2' x = if x < 10 then [ ', ', intToDigit x] else show2 x
show3 x = intToDigit (x 'quot' 100) : show2 (x 'rem' 100)
15 Locale

module Locale(TimeLocale(..), defaultTimeLocale) where

data TimeLocale = TimeLocale {
    wDays :: [(String, String)], -- full and abbreviated week days
    months :: [(String, String)], -- full and abbreviated months
    amPm :: (String, String), -- AM/PM symbols
    dateTimeFmt, dateFormat,
    timeFmt, time12Fmt :: String
} deriving (Eq, Ord, Show)

defaultTimeLocale :: TimeLocale

The Locale library provides the ability to adapt to local conventions. At present, it supports only time and date information as used by calendarTimeToString from the Time library.
15.1 Library Locale

module Locale(TimeLocale(..), defaultTimeLocale) where

data TimeLocale = TimeLocale {
    wDays :: [(String, String)],  -- full and abbreviated week days
    months :: [(String, String)], -- full and abbreviated months
    amPm :: (String, String),   -- AM/PM symbols
    dateTimeFmt, dateFmt,      -- formatting strings
    timeFmt, time12Fmt :: String
} deriving (Eq, Ord, Show)

defaultTimeLocale :: TimeLocale

defaultTimeLocale = TimeLocale {
    wDays = ["Sunday", "Sun"],  -- full and abbreviated week days
                    ["Monday", "Mon"],
                    ["Tuesday", "Tue"],  -- full and abbreviated months
                    ["Wednesday", "Wed"],
                    ["Thursday", "Thu"],
                    ["Friday", "Fri"],
                    ["Saturday", "Sat"],
    months = ["January", "Jan"],  -- full and abbreviated months
                    ["February", "Feb"],
                    ["March", "Mar"],
                    ["April", "Apr"],
                    ["May", "May"],
                    ["June", "Jun"],
                    ["July", "Jul"],
                    ["August", "Aug"],
                    ["September", "Sep"],
                    ["October", "Oct"],
                    ["November", "Nov"],
                    ["December", "Dec"],
    amPm = ("AM", "PM"),
    dateTimeFmt = "%a %b %e %H:%M:%S %Z %Y",
    dateFmt = "%m/%d/%y",
    timeFmt = "%H:%M:%S",
    time12Fmt = "%I:%M:%S %p"
}
16 CPU Time

```haskell
module CPUPTime ( getCPUPtime ) where

getCPUPtime :: IO Integer
cpuTimePrecision :: Integer
```

Computation getCPUPtime returns the number of picoseconds of CPU time used by the current program. The precision of this result is given by cpuTimePrecision. This is the smallest measurable difference in CPU time that the implementation can record, and is given as an integral number of picoseconds.
17 Random Numbers

```
module Random (  
    RandomGen(next, split),  
    StdGen, mkStdGen,  
    Random(random, randomR,  
        randoms, randomRs,  
        randomIO, randomRIO ),  
    getStdRandom, getStdGen, setStdGen, newStdGen  
) where

--------------- The RandomGen class ---------------

class RandomGen g where
    next :: g -> (Int, g)
    split :: g -> (g, g)

--------------- A standard instance of RandomGen ------------
data StdGen = ... -- Abstract

instance RandomGen StdGen where ...
instance Read StdGen where ...
instance Show StdGen where ...

mkStdGen :: Int -> StdGen

--------------- The Random class -------------------

class Random a where
    randomR :: RandomGen g => (a, a) -> g -> (a, g)
    random :: RandomGen g => g -> (a, g)
    randomRs :: RandomGen g => (a, a) -> g -> [a]
    randoms :: RandomGen g => g -> [a]
    randomRIO :: (a,a) -> IO a
    randomIO :: IO a

instance Random Int where ...
instance Random Integer where ...
instance Random Float where ...
instance Random Double where ...
instance Random Bool where ...
instance Random Char where ...

--------------- The global random generator --------------

newStdGen :: IO StdGen
setStdGen :: StdGen -> IO ()
getStdGen :: IO StdGen
getStdRandom :: (StdGen -> (a, StdGen)) -> IO a
```
The Random library deals with the common task of pseudo-random number generation. The
library makes it possible to generate repeatable results, by starting with a specified initial
random number generator; or to get different results on each run by using the system-
initialised generator, or by supplying a seed from some other source.

The library is split into two layers:

- A core *random number generator* provides a supply of bits. The class RandomGen
  provides a common interface to such generators.

- The class Random provides a way to extract particular values from a random number
  generator. For example, the Float instance of Random allows one to generate random
  values of type Float.

### 17.1 The RandomGen class, and the StdGen generator

The class RandomGen provides a common interface to random number generators.

```haskell
class RandomGen g where
  next :: g -> (Int, g)
  split :: g -> (g, g)
```

- The `next` operation allows one to extract at least 30 bits (one Int's worth) from the
  generator, returning a new generator as well. The integer returned may be positive or
  negative.

- The `split` operation allows one to obtain two distinct random number generators.
  This is very useful in functional programs (for example, when passing a random num-
  ber generator down to recursive calls), but very little work has been done on statisti-
  cally robust implementations of `split` ([1,4] are the only examples we know of).

The Random library provides one instance of RandomGen, the abstract data type StdGen:

```haskell
data StdGen = ... -- Abstract

instance RandomGen StdGen where ...
instance Read StdGen where ...
instance Show StdGen where ...

mkStdGen :: Int -> StdGen
```

The result of repeatedly using `next` should be at least as statistically robust as the “Minimal
Standard Random Number Generator” described by [2,3]. Until more is known about
implementations of `split`, all we require is that `split` deliver generators that are (a) not
identical and (b) independently robust in the sense just given.

The `show/Read` instances of StdGen provide a primitive way to save the state of a random
number generator. It is required that `read (show g) == g`. 
In addition, read may be used to map an arbitrary string (not necessarily one produced by show) onto a value of type StdGen. In general, the read instance of StdGen has the following properties:

- It guarantees to succeed on any string.
- It guarantees to consume only a finite portion of the string.
- Different argument strings are likely to result in different results.

The function mkStdGen provides an alternative way of producing an initial generator, by mapping an Int into a generator. Again, distinct arguments should be likely to produce distinct generators.

Programmers may, of course, supply their own instances of RandomGen.

### 17.2 The Random class

With a source of random number supply in hand, the Random class allows the programmer to extract random values of a variety of types:

```haskell
class Random a where
    randomR :: RandomGen g => (a, a) -> g -> (a, g)
    random  :: RandomGen g => g -> (a, g)
    randomRs :: RandomGen g => (a, a) -> g -> [a]
    randoms :: RandomGen g => g -> [a]
    randomIO :: (a,a) -> IO a
    randomIO :: IO a

    -- Default methods
    randoms g = x : randoms g'
        where
            (x,g') = random g
    randomRs = ...similar...
    randomIO = getRandoms random
    randomIO range = getRandoms (randomR range)
```

```haskell
instance Random Int where ...
instance Random Integer where ...
instance Random Float where ...
instance Random Double where ...
instance Random Bool where ...
instance Random Char where ...
```
- `randomR` takes a range \((lo, hi)\) and a random number generator \(g\), and returns a random value uniformly distributed in the closed interval \([lo, hi]\), together with a new generator. It is unspecified what happens if \(lo > hi\). For continuous types there is no requirement that the values \(lo\) and \(hi\) are ever produced, but they may be, depending on the implementation and the interval.

- `random` does the same as `randomR`, but does not take a range.
  
  - For bounded types (instances of `Bounded`, such as `Char`), the range is normally the whole type.
  
  - For fractional types, the range is normally the semi-closed interval \([0, 1)\).
  
  - For `Integer`, the range is (arbitrarily) the range of `Int`.

- The plural versions, `randomRs` and `randoms`, produce an infinite list of random values, and do not return a new generator.

- The IO versions, `randomRIO` and `randomIO`, use the global random number generator (see Section 17.3).

### 17.3 The global random number generator

There is a single, implicit, global random number generator of type `StdGen`, held in some global variable maintained by the IO monad. It is initialised automatically in some system-dependent fashion, for example, by using the time of day, or Linux's kernal random number generator. To get deterministic behaviour, use `setStdGen`.

```haskell
setStdGen :: StdGen -> IO ()
getStdGen :: IO StdGen
newStdGen :: IO StdGen
getStdRandom :: (StdGen -> (a, StdGen)) -> IO a
```

- `getStdGen` and `setStdGen` get and set the global random number generator, respectively.

- `newStdGen` applies `split` to the current global random generator, updates it with one of the results, and returns the other.

- `getStdRandom` uses the supplied function to get a value from the current global random generator, and updates the global generator with the new generator returned by the function. For example, `rollDice` gets a random integer between 1 and 6:

```haskell
rollDice :: IO Int
rollDice = getStdRandom (randomR (1,6))
```
References


The Web site http://random.mat.sbg.ac.at/ is a great source of information.
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