A Musical Offering

Composing functions composing music

A Little Haskell

Functions!

```
simple ab = a + b
simple 11 --2
```

Lists! Cons-es!

```
1 = 1:2:3:[]
--[1,2,3]
1:[2,3]
```

Pattern matching!

```
add2 [] = []
add2 (x:xs) = (2 + x) : (add2 xs)
add2 [1,2,3]
--[3,4,5]
```

A taste of Euterpea

What's a note?

```
concertA = (A, 4) --Tuple
quarterNote = 1/4 --Rational
qnA = note quarterNote concertA
```

Some functions that ship with Euterpea

```
qnA' = a 4 qn
play qnA'
staccatos = (d 4 en) :+: dqnr :+: (fs 4 en)
play (tempo 3 staccatos)
play $ tempo 3 staccatos
play $ instrument ChurchOrgan staccatos
```

Composing music

```
doReMi = c 4 qn :+: d 4 qn :+: e 4 qn
cMaj = c 4 qn :=: e 4 qn :=: g 4 qn
play doReMi
play cMaj
play (doReMi :+: cMaj)
```

Composing music

A familiar tune

```
fJacques =
    g 4 qn :+: a 4 qn :+: b 4 qn :+: g 4 qn :+:
    b 4 qn :+: c 5 qn :+: d 5 hn :+:
    d 5 den :+: e 5 sn :+: d 5 en :+:
    c 5 en :+: b 4 qn :+: g 4 qn :+:
    g 4 qn :+: e 4 qn :+: g 4 hn

play $ instrument Flute $ tempo 2

fJacques
```

Composing music

Another familiar tune

```
ludwigVan =
  (g 1 en :=: g 2 en :=: g 3 en :=: g 4 en) :+:
  (g 1 en :=: g 2 en :=: g 3 en :=: g 4 en) :+:
  (g 1 en :=: g 2 en :=: g 3 en :=: g 4 en) :+:
  (ef 1 dhn :=: ef 2 dhn :=: ef 3 dhn :=: ef 4 dhn) :+:
  denr :+:
  (f 1 en :=: f 2 en :=: f 3 en :=: f 4 en) :+:
  (f 1 en :=: f 2 en :=: f 3 en :=: f 4 en) :+:
  (f 1 en :=: f 2 en :=: f 3 en :=: f 4 en) :+:
  (d 1 dhn :=: d 2 dhn :=: d 3 dhn :=: d 4 dhn)
  play ludwigVan
```

The name of the wind

Type synonyms:

```
type Octave = Int
type Pitch = ( PitchClass, Octave )
type Dur = Rational
data PitchClass = Cff | Cf | C | Dff | Cs |
Df | Css | D --...
```

Haskell infers types, but we can tell it too:

```
qn :: Dur
qn = 1/4
(A, 4) :: Pitch
add2 :: [Int] -> [Int]
note :: Dur -> Pitch -> Music Pitch
a,b,c,d,e,f,g :: Octave -> Dur -> Music
Pitch
```

A Type of Music

Basic units of music:

We can think about these 'constructors' as functions:

```
Note :: Dur -> Pitch -> Primitive
```

Rest :: Dur -> Primitive

Okay definition... but notes are more than pitches (percussion, volume, etc.)

Which looks like:

Note :: Dur -> a -> Primitive a

Rest:: Primitive a

A fancier (recursive!) type

Music is not just single notes

Reasoning with types

```
line :: [Music a] -> Music a
line [] = rest 0
line (m:ms) = m :+: line ms
line [c 4 qn, e 4 qn, g 4 qn, c 5 qn]
How would we build the chord function?
```

```
chord :: [Music a] -> Music a
chord [] = rest 0
chord (m:ms) = m :=: chord ms
```

Pattern matching, TNG

```
majChord :: Music Pitch -> Music Pitch
majChord n =
    n :=:
    transpose 4 n :=:
    transpose 7 n
```

Pattern matching, TNG

```
majChord :: Music Pitch -> Music Pitch
majChord (Prim (Note d root)) =
   note d root :=:
   note d (trans 4 root) :=:
   note d (trans 7 root)
majChord _ = error 'only works for
notes!'
```

Pattern matching, TNG

```
majChord :: Music Pitch -> Music Pitch
majChord (Prim (Note d r@ (pc, oct))) =
  note d r :=:
  note d (trans 4 r) :=:
  note d (trans 7 r) :=:
  note d (pc, o+1))
majChord _ = error 'only works for
notes!'
```

Fancier functions

Haskell ships with some pretty cool functions

```
foldr (+) 0 [1,2,3] --6
scanl (+) 10 [1,2,3] -- [10,11,13,16]
foldr1 (+) [1,2,3]
[1,2,3] !! 1 --2
take 2 [1,2,3] --[1,2]
reverse [1,2,3] -- [3,2,1]
twice x = x*2
map twice [1,2,3] -- [2,4,6]
plus2 x = x+2
map (twice . plus2) [1,2,3] -- [6,8,10]
```

Fancier functions

And their signatures are very interesting. Can you guess them?

```
reverse :: [a] -> [a]

take :: Int -> [a] -> [a]

scanl :: (b -> a -> b) -> b -> [a] -> [b]

(!!) :: [a] -> Int -> a

(.) :: (b -> c) -> (a -> b) -> a -> c
```

Fancier functions

You can use them for music:

```
mystery1 :: [Music a] -> Music a
mystery1 ns = foldr1 (:+:) ns
```

Haskell: Curry

Partial application is the default:

```
add a b = a + b
add2 = add 2
add2 40 - 42
(add 2) 40
```

Which comes in handy:

```
line = foldr1 (:+:)
chord = foldr1 (:=:)
```

Haskell is lazy

And lazy evaluation is also a default:

```
forever :: Music x -> [ Music x ]
forever m = m : forever m
foreverA o dur = forever $ a o dur
foreverA4qn = foreverA 4 qn
No explosions, until...
```

play \$ line \$ take 2 foreverA4qn

How would we build a scale?

What we want:

mkScale [2,2,3,2] (fs 4 qn)
--Fs,Gs,As,Cs,Ds

How would we build a scale?

In Music:



How would we build a scale?

In English:

- Take a list of intervals
- Get each abs pitch relative to the root
- (e.g. [0, 0+2, 2+2, 4+3, 7+2]
- Turn those abs pitches into a list of notes

How would we build a scale?

In Haskell:

```
mkScale :: [Int] -> Music Pitch -> [Music
Pitch]
mkScale ints ( Prim ( Note d p) ) =
  map (note qn . pitch) $
  scanl (+) (absPitch p) ints
```

How would we build a scale?

Which we can use to define stuff:

```
pentatonic = mkScale [2,2,3,2]
blackKeys = pentatonic $ fs 4 qn
play $ line blackKeys
```

How would we build a scale?

Or we can go crazy

```
mkScale ints ( Prim ( Note d p) ) =
  map (note qn . pitch) $
  scanl (+) (absPitch p) (cycle ints)

mkChord scale degrees =
  chord $
  map ((scale!!) . (subtract 1))
    degrees
```

How would we build a scale?

What do these do?

```
cMaj = mkScale [2,2,1,2,2,2,1] (c 4 qn)
play $ line $ take 16 cMaj
play $ mkChord cMaj [1,5,8,9,11]
```

A musical puzzle

Bach's 'Crab Canon'

All the score says is Canon 1 a 2



Hint: there's a weird extra clef...

We need to play it from both ends!

Let's transcribe it first

Some helper functions

```
lineToList :: Music a -> [Music a]
lineToList (Prim (Rest 0)) = []
lineToList (n :+: ns) = n : lineToList ns
retrograde :: Music Pitch -> Music Pitch
retrograde = line . reverse . lineToList
staccato :: Music a -> Music a
staccato (Prim (Note d p)) =
  note (d/8) p :+: rest (7*d/8)
```

And play that:

```
crabCanon :: Music Pitch
crabCanon =
  instrument Harpsichord $
  crabTheme :=:
  retrograde crabTheme
```

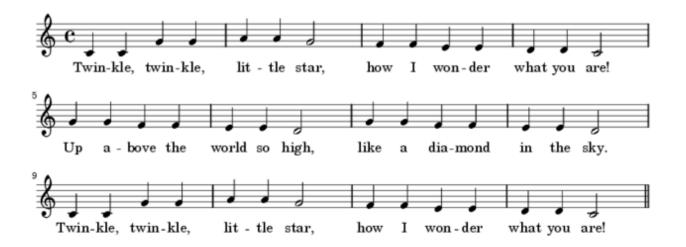
Takeaways

- Rephrase problems in terms of existing solutions
- Find the glue in your language (in Haskell: lazy, partial, high-ordered, functions)
- A clever type system can be a powerful tool, not a boilerplate prison
- Programming can be a tool to approach art, too!

Appendix

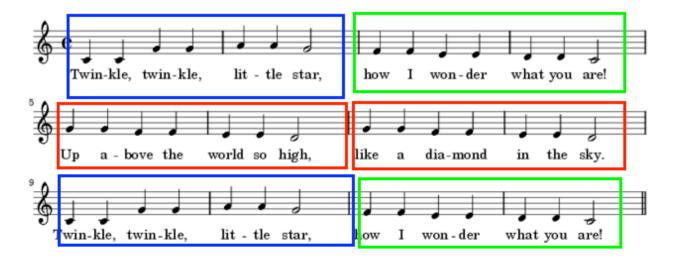
Let's use our knowledge for music!

Remember this tune?



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Remember this tune?

```
pcToQn :: PitchClass -> Music Pitch
pcToQn pc = note qn (pc, 4)
twinkle =
  let m1 = line (map pcToQn
[C,C,G,G,A,A]) :+: q 4 hn
      m2 = line (map pcToQn
[F,F,E,E,D,D]):+: c 4 hn
      m3 = line (map pcToQn
[G,G,F,F,E,E]) :+: d 4 hn
  in line [m1, m2, m3, m3, m1, m2]
```

Playing with music

```
times 0 m = rest 0; times n m = m :+: times
(n - 1) m
play $ twinkle :=: ((times 2 (rest hn)))
:+: twinkle)

What if we want to generalize it?

canon :: (Int, Dur) -> Music a -> Music a
canon (2, hn) twinkle
```

A function for creating canons:

```
canon :: (Int, Dur) -> Music a -> Music a
canon (voices, delay) mel =
  let range n = take n [0..]
    wait d m n = times n (rest dur) :+: m
  in chord $ map
    (wait delay mel) (range voices)
```

With some interesting results:

```
play $ canon (2, hn) twinkle
play $ canon (2, qn) twinkle
play $ canon (2, en) twinkle
```