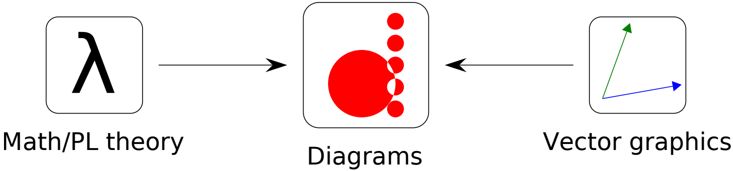
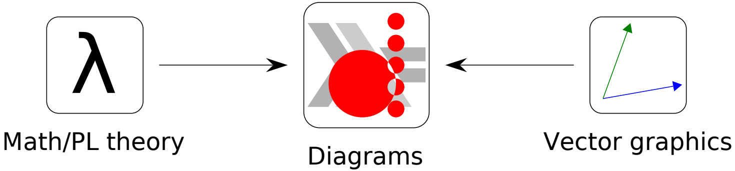
Declarative, Programmatic Vector Graphics in Haskell

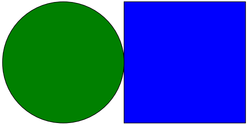
Brent Yorgey

Libre Graphics Meeting
Leipzig
3 April, 2013

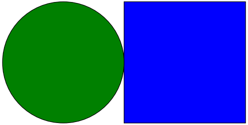

λ
Math/PL theory
Diagrams
Vector graphics



Embedded in Haskell.

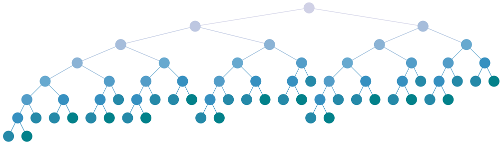


```
circle 1 # fc green ||| square 2 # fc blue
```



```
circle 1 # fc green ||| square 2 # fc blue
```

Look ma, no coordinates!



```
fib 0 = leaf 0; fib 1 = leaf 1
fib n = BNode n (fib (n-1)) (fib (n-2))

tree
  = renderTree'
      (\i -> circle 0.3 # lw 0 # fc (colors !! i))
      (\(i,p) (_,q) -> p ~~ q # lc (colors !! i))
  . fromJust . symmLayoutBin $ fib 8
```

Haskell and EDSLs

Haskell makes a great host language for DSLs:

- strong static type system
- first-class functions
- powerful abstraction mechanisms
- culture that encourages elegant, mathematically-based design: theory meets practice

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Full disclosure:

- Error messages suck

Types

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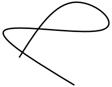
points

paths

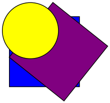


vectors

transformations

colors

diagrams



Impossible to make silly mistakes like applying a vector to a color, or adding two points.

Functions

Haskell has **first-class functions**.

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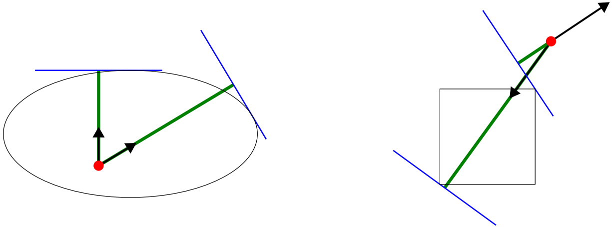

Abstraction

Haskell has **powerful abstraction mechanisms**.

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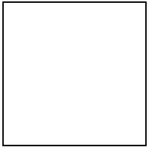

```
square :: Double -> Diagram
```

Abstraction

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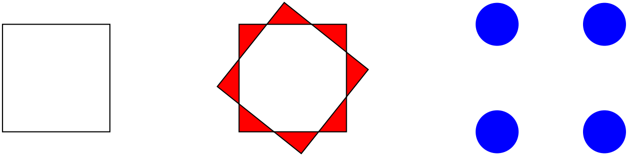

```
square :: (TrailLike t, Transformable t, V t ~ R2)
       => Double -> t
```

Design

Haskell encourages **elegant, mathematically-based design**.

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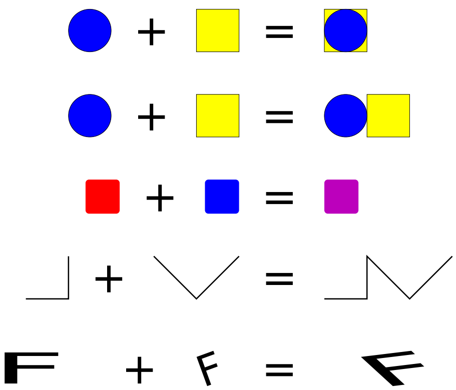

Design

Monoids: Theme and Variations *(Functional Pearl)*

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Abstract

The *monoid* is a humble algebraic structure, at first glance even downright boring. However, there's much more to monoids than meets the eye. Using examples taken from the diagrams vector graphics framework as a case study, I demonstrate the power and beauty of monoids for library design. The paper begins with an extremely simple model of diagrams and proceeds through a series of incremental variations, all related somehow to the central theme of monoids. Along the way, I illustrate the power of compositional semantics; why you should also pay attention to the monoid's even humbler cousin, the *semigroup*; monoid homomorphisms; and monoid actions.

Categories and Subject Descriptors D.1.1 [*Programming Techniques*]: Applicative (Functional) Programming; D.2.2 [*Design Tools and Techniques*]

General Terms Languages, Design

Keywords monoid, homomorphism, monoid action, EDSL

Prelude

diagrams is a framework and embedded domain-specific language for creating vector graphics in Haskell.[1] All the illustrations in this paper were produced using diagrams, and all the examples inspired by it. However, this paper is not really about diagrams at all! It is really about *monoids*, and the powerful role they—and, more generally, any mathematical abstraction—can play in library design. Although diagrams is used as a specific case study, the central ideas are applicable in many contexts.

Theme

What is a *diagram*? Although there are many possible answers to this question (examples include those of Elliott [2003] and Matlage and Gill [2011]), the particular semantics chosen by diagrams is an *ordered collection of primitives*. To record this idea as Haskell code, one might write:

```
type Diagram = [Prim]
```

But what is a *primitive*? For the purposes of this paper, it doesn't matter. A primitive is a thing that Can Be Drawn—like a circle, arc, polygon, Bézier curve, and so on—and inherently possesses any attributes we might care about, such as color, size, and location.

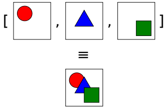


Figure 1. Superimposing a list of primitives

The primitives are ordered because we need to know which should appear "on top". Concretely, the list represents the order in which the primitives should be drawn, beginning with the "bottommost" and ending with the "topmost" (see Figure 1).

Lists support *concatenation*, and "concatenating" two Diagrams also makes good sense: concatenation of lists of primitives corresponds to *superposition* of diagrams—that is, placing one diagram on top of another. The empty list is an identity element for concatenation ($[\,] +\!\!+\, xs = xs +\!\!+ [\,] = xs$), and this makes sense in the context of diagrams as well: the empty list of primitives represents the *empty diagram*, which is an identity element for superposition. List concatenation is associative; diagram A on top of (diagram B on top of C) is the same as (A on top of B) on top of C. In short, $(+\!\!+)$ and $[\,]$ constitute a *monoid* structure on lists, and hence on diagrams as well.

This is an extremely simple representation of diagrams, but it already illustrates why monoids are so fundamentally important: *composition* is at the heart of diagrams—and, indeed, of many libraries. Putting one diagram on top of another may not seem very expressive, but it is the fundamental operation out of which all other modes of composition can be built.

However, this really is an extremely simple representation of diagrams—much *too* simple! The rest of this paper develops a series of increasingly sophisticated variant representations for Diagram, each using a key idea somehow centered on the theme of monoids. But first, we must take a step backwards and develop this underlying theme itself.

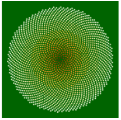
Interlude

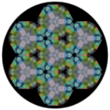
The following discussion of monoids—and the rest of the paper in general—relies on two simplifying assumptions:

[1] `http://projects.haskell.org/diagrams/`

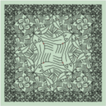
Haskell '12, September 13, 2012, Copenhagen, Denmark.

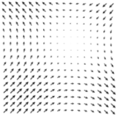
Examples


Sunflower

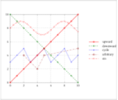

Kaleidoscope

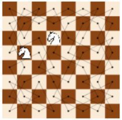

Sunburst partition

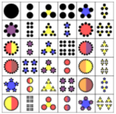

Square Limit


Vector field


Symmetry Cube


Simple Chart


Knight tour


Factorization diagrams

Examples

What's next?

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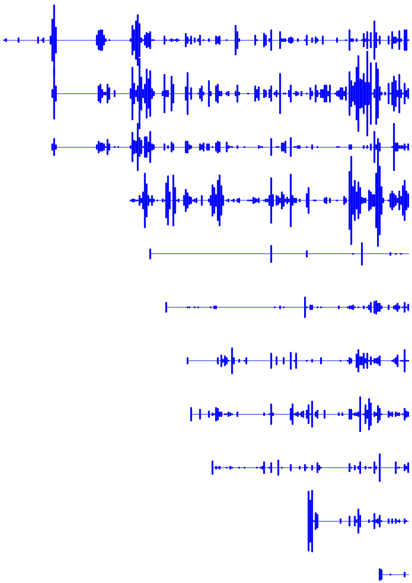
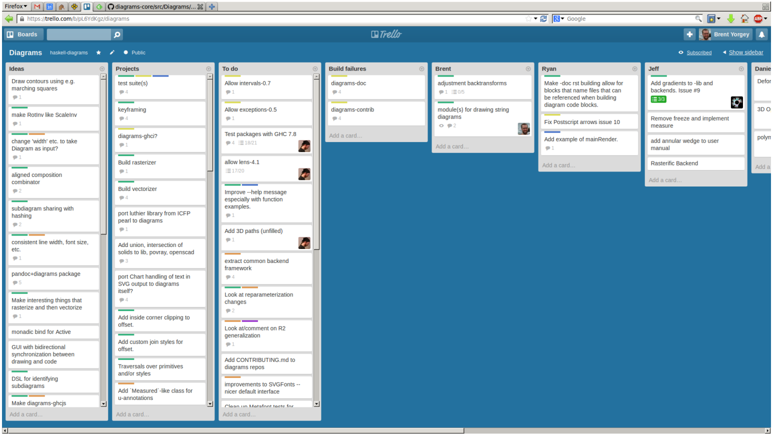


What's next?



Diagrams
Ideas
Draw contours using e.g. marching squares
make RotInv like ScaleInv
change 'width' etc. to take Diagram as input?
aligned composition combinator
subdiagram sharing with hashing
consistent line width, font size, etc.
pandoc+diagrams package
Make interesting things that rasterize and then vectorize
monadic bind for Active
GUI with bidirectional synchronization between drawing and code
DSL for identifying subdiagrams
Make diagrams-ghcjs
Projects
test suite(s)
keyframing
diagrams-ghci?
Build rasterizer
Build vectorizer
port luthier library from ICFP pearl to diagrams
Add union, intersection of solids to lib, povray, openscad
port Chart handling of text in SVG output to diagrams itself?
Add inside corner clipping to offset.
Add custom join styles for offset.
Traversals over primitives and/or styles
Add `Measured`-like class for u-annotations
To do
Allow intervals-0.7
Allow exceptions-0.5
Test packages with GHC 7.8
allow lens-4.1
Improve --help message especially with function examples.
Add 3D paths (unfilled)
extract common backend framework
Look at reparameterization changes
Look at/comment on R2 generalization
Add CONTRIBUTING.md to diagrams repos
improvements to SVGFonts -- nicer default interface
Build failures
diagrams-doc
diagrams-contrib
Brent
adjustment backtransforms
module(s) for drawing string diagrams
Ryan
Make -doc rst building allow for blocks that name files that can be referenced when building diagram code blocks.
Fix Postscript arrows issue 10
Add example of mainRender.
Jeff
Add gradients to -lib and backends. Issue #9
Remove freeze and implement measure
add annular wedge to user manual
Rasterific Backend

What's next?

- Google Summer of Code project to allow **editing** diagrams.

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- Animations and interactivity.
- Bidirectional GUI/code editor.
- Open to suggestions!

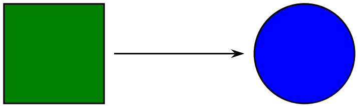
http://projects.haskell.org/diagrams

Extra slides

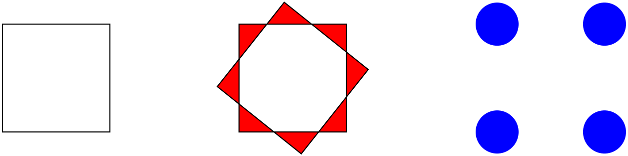
Backends

and:

- OpenGL
- HTML5 canvas
- PGF/TikZ
- PDF
- native Haskell raster library



```
shapes = hcat' (with & sep .~ 3)
       [ square 2  # fc green  # named "s"
       , circle 1  # fc blue   # named "c"
       ]
dia = shapes
    # connectOutside' (with & gap .~ 0.2)
      "s" "c"
```



```
dia = hcat' (with & sep .~ 1)
  [ square 1
  , mconcat
    [ square 1
    , square 1 # reversePath # rotateBy (1/7))
    ]
    # stroke # fc red
  , square 1 # map (place dot) # mconcat
  ]
  where
    dot = circle 0.2 # fc blue # lw 0
```