

## Semantic Design

The following is what I call a 'semantic design' (as well as an unrelated replacement for micro-services called MetaFunctions). The concept of a semantic design is inspired by Conal Elliot's denotational design - <https://www.youtube.com/watch?v=bmKYiUOEo2A>.

To specify semantic designs generally, I've created a meta-language called SEDELA (for Semantic Design Language). First, we present the definition of SEDELA, then the semantic design for MetaFunctions in terms of SEDELA. Although I may aim to write a parser and type-checker for SEDELA, there will never be a compiler or interpreter. Thus, SEDELA will have no syntax for **if** expressions and the like. The only Meanings (SEDELA's nomenclature for functions) defined in the Prelude will be combinators such as `id`, `const`, `flip`, and etc. SEDELA's primitive types are all defined in terms of Axioms (types without formal definitions) with no available operations.

To understand Sedela, it is useful to talk about its intended capabilities as well as how it contrasts with denotational design.

The first intended capability of Sedela is to allow program designers to encode their program's abstract structure separate from and - as much as possible, prior to! - its implementation. I believe that getting a program's abstract structure correct is the most important task of program design and that doing so up front yields maximal benefits. Also important is encoding the program's abstract structure in a way that is not limited by the implementation language - in particular by its type system, such as with dynamic, weak, or ad-hoc type systems (see lisp, python, or any object-oriented language).

The second intended capability of Sedela is to allow program designers to specify their program's intended structure in one of two ways - in a formal, compositional way (terms defined entirely in terms of other fully defined terms), or in an informal, textual way (terms defined with just descriptive text). Where a formal approach is required, Sedela allows designers to encode their program's abstract terms in terms of algebraic data types and a typed lambda calculus (here System  $F^s$  with Type Families). Where a more informal approach is permitted, Sedela offers designers the ability to define their terms with 'axioms'. The less formal definitions enabled by 'axioms' makes Sedela a usable tool for describing systems that may be too complex to warrant formal specification, in particular, for legacy programs.

I currently contrast Sedela's semantic design with Conal's denotational design as follows -

- 1) Denotational design requires no specialized host language whereas semantic design requires something like the small one specified in this document.
- 2) Denotational design restricts its domain of use to programs / subprograms whose structure can be specified denotatively (IE, formally and in full). This is an advantage for those working on greenfield projects and on projects that otherwise demand formal definition (such as with programming languages).
- 3) Semantic design provides a 'knob' for the level of detail at which designers would like to specify their programs. It has been found to be useful to increase the level of detail for designs by replacing some informal definitions with more detailed ones (terms defined in terms of other terms) while leaving less detailed other definitions for brevity or temporary convenience. Semantic design may end up being a useful bridge from a low-detail 'on-napkins' design to one that can (and should be) specified denotatively with denotational design.

While denotative design seems ideal, I invented semantic design for either one of two reasons - 1) I could not apply denotational

design to my current needs due to its limited domain of application, or 2) I did not understand denotative design well enough to realize its domain of application was big enough to in fact satisfy my needs. Denotational design is admittedly still a mystery to me in some ways, so while I am confident in Sedela's utility, I am not entirely confident that Sedela cannot be entirely subsumed by denotational design. To me, it remains to be seen.

## Sedela Language Definition

<b>Axiom</b> :=	Axiom[!] "Informal (textual) definition."	where ! denotes intended effectfulness
<b>Meaning Type</b> :=	A -> ... -> Z	where A ... Z are <b>Type Expressions</b>
<b>Meaning Defn</b> :=	let f (a : A) ... (z : Z) : R = <b>Expression</b>   <b>Axiom</b>	where f is the <b>Meaning Identifier</b> and a ... z are <b>Parameter Identifiers</b> and A ... Z, R are <b>Type Expressions</b>
<b>Derivation</b> :=	<b>Nested Example:</b> f a (g b)	where f and g are a <b>Meaning Identifiers</b> and a and b are <b>Binding Identifiers</b>
<b>Product</b> :=	let MyProduct<...> = A   ( <b>A</b> : A, ..., <b>Z</b> : Z)   <b>Axiom</b>	where MyProduct<...> is the <b>Product Identifier</b> and <b>A</b> ... <b>Z</b> are <b>Field Identifiers</b> and A ... Z are <b>Type Expressions</b>
<b>Sum</b> :=	let MySum<...> =   <b>A</b> of (A   <b>Axiom</b> )   ...   <b>Z</b> of (Z   <b>Axiom</b> )	where MySum<...> is the <b>Sum Identifier</b> and <b>A</b> ... <b>Z</b> are <b>Case Identifiers</b> and A ... Z are <b>Type Expressions</b>
<b>Type Identifier</b> :=	<b>Product Identifier</b>   <b>Sum Identifier</b>	
<b>Type Expression</b> :=	<b>Meaning Type</b>   <b>Type Identifier</b>	
<b>Type Parameters</b> :=	<b>Type Identifier</b> < A, ..., Z; <b>A</b> <A, ..., Z>; ...; <b>Z</b> <...>>	where A ... Z are <b>Type Expressions</b> and <b>A</b> ... <b>Z</b> are <b>Category Identifiers</b> used for constraining A ... Z
<b>Category</b> :=	category MyCat<...> = f : A ... g : Z	where MyCat<...> is the <b>Category Identifier</b> and f ... g are <b>Equivlence Identifiers</b> and A ... Z are <b>Types Expressions</b>
<b>Witness</b> :=	witness <b>A</b> = f (a : A) ... (z : Z) : R = <b>Expression</b> ... g (a : A) ... (z : Z) : R = <b>Expression</b>	where <b>A</b> is a <b>Category Identifier</b> and f ... g are <b>Equivlence Identifiers</b> and a ... z are <b>Parameter Identifiers</b> and A ... Z, R are <b>Type Expressions</b>
<b>Categorization</b> :=	<b>Rule:</b> iff type A has a witness for category <b>A</b> , A is allowable for type parameter categorized as <b>A</b>	

**Line Comment** :=           **Example:** // comment text

fun a b ... z -> expr := \a (\b (... \z.expr))

a -> b :=                   let \_ = (\_ : a) : b

() :=                   **Explanation:** The unit type / value.

f . g :=                   **Explanation:** Function composition.

Any? :=                   **Explanation:** The universal subtype. Only types that end with '?' allow for substitution (this preserving free theorems elsewhere).

## Sedela Language Prelude

```
let Bool = Axiom "A binary type."  
let Real = Axiom "A real number type."  
let Whole = Axiom "A whole number type."  
let String = Axiom "A textual type."  
let Maybe<a> = | Some of a | None  
let Either<a, b> = | Left of a | Right of b  
let List<a> = | Nil | Link of (a, List<a>)  
let Map<a, b> = | Leaf of (a, b) | Node of (Map<a, b>, Map<a, b>)
```

```
category Semigroup<a> =  
  append : a -> a -> a
```

```
category Monoid<m; Semigroup<m>> =  
  empty : m
```

```
category Functor<f> =  
  map<a, b> : (a -> b) -> f<a> -> f<b>
```

```
category Pointed<p> =  
  pure<a> : a -> p<a>
```

```
category FunctorPointed<f; Functor<f>; Pointed<f>>
```

```
category Applicative<p; FunctorPointed<p>> =  
  apply<a, b> : p<a -> b> -> p<a> -> p<b>
```

```
category Monad<m; Applicative<m>> =  
  bind<a, b> : m<a> -> (a -> m<b>) -> m<b>
```

```
category Alternative<l; Applicative<l>> =  
  empty<a> : l<a>  
  choice : l<a> -> l<a> -> l<a>
```

```
category Comonad<c; Functor<c>> =  
  extract<a> : c<a> -> a  
  duplicate<a, b> : c<a> -> c<c<a>>  
  extend<a, b> : (c<a> -> b) -> c<a> -> c<b>
```

```
category Arrow<a; Category<a>> =  
  arr<b, c> : (b -> c) -> a<b, c>  
  first<b, c, d> : a<b, c> -> a<(b, d), (c, d)>
```

```

category ArrowChoice<a; Arrow<a>> =
  left<b, c, d> : a<b, c> -> a<Either<b,d>, Either<c, d>>

category ArrowApply ... // TODO: implement!

category ArrowLoop ... // TODO: implement

category Foldable<f> =
  fold<a, b> : (b -> a -> b) -> f<a> -> b

category Traversable<t; Functor<t>; Foldable<t>> =
  traverse<a, b, p; Applicative<f>> : (a -> p<b>) -> t<a> -> p<t<b>>

category Functor2<g; Functor<g>> =
  map2<a, b, c> : g<a> -> g<b> -> g<c>

category Producibile<p; Functor2<p>> =
  product<a, b> : p<a> -> p<b> -> p<(a, b)>

category Summable<s; Producibile<s>> =
  sum<a, b> : s<a> -> s<b> -> s<Either<a, b>>

category Foldable2<f; Foldable<f>> =
  fold2<a, b, c> : (c -> a -> b -> c) -> f<a> -> f<b> -> c

category Category<t> =
  id<a> : t<a, a>
  compose<a, b, c> : t<b, c> -> t<a, b> -> t<a, c>

category Cartesian<k; Category<k>> = // taken from Conal Elliott's talk "Compiling to Categories"
  type Cross<u, v> // a type alias family member
  exl : k<Cross<a, b>, a>
  exr : k<Cross<a, b>, b>
  fork : k<a, c> -> k<a, d> -> k<a, Cross<c, d>>

category Cocartesian<k; Category<k>> =
  type Plus<u, v>
  inl : k<a, Plus<a, b>>
  inr : k<b, Plus<a, b>>
  join : k<a, c> -> k<a, d> -> k<Cross<c, d>, a>

```

```
category CartesianClosed<k; Cartesian<k>> =  
  type Yield<a, b>  
  apply : k<Cross<Yield<a, b>, a>, b>  
  curry : k<Cross<a, b>, c> -> k<a, Yield<b, c>>  
  uncurry : k<a, Yield<b, c>> -> k<Cross<a, b>, c>
```

```
let const a _ = a  
let flip f a b = f b a
```

## Semantic Design for MetaFunctions (a replacement for micro-services)

```
let Symbol =
  Atom of String
  Number of String
  String of String
  Quote of Symbol
  Symbols of List<Symbol>
let symbolToString (symbol : Symbol) : String = Axiom "Convert a symbol to string."
let symbolFromString (str : String) : Symbol = Axiom "Convert a string to a symbol."

let Vsync<a> =
  Axiom "The potentially asynchronous monad such as the one defined by Prime."
let vsyncReturn<a> (a : a) : Vsync<a> =
  Axiom "Create a potentially asynchronous operation that returns the result 'a'."
let vsyncMap<a, b> (f : a -> b) (vsync : Vsync<a>) : Vsync<b> =
  Axiom "Create a potentially asynchronous operation that runs 'f' over computation of 'a'."
let vsyncApply<a, b> (f : Vsync<a> -> Vsync<b>) (vsync : Vsync<a>) : Vsync<b> =
  Axiom "Apply a potentially asynchronous operation to a potentially asynchronous value"
let vsyncBind<a, b> (vsync : Vsync<a>) (f : a -> Vsync<b>) : Vsync<b> =
  Axiom "Create a potentially asynchronous operation."

witness Monad =
  pure = vsyncReturn
  map = vsyncMap
  apply = vsyncApply
  bind = vsyncBind

let IPAddress = String
let NetworkPort = Whole
let Endpoint = (IPAddress, NetworkPort)
let Intent = String // the intended meaning of a MetaFunction (indexes a MetaFunction from a Provider - see below)
let Container = Intent -> Symbol -> Vsync<Symbol>
let Provider = | Endpoint | Container
let MetaFunction = Provider -> Intent -> Symbol -> Vsync<Symbol>

let makeContainer (asynchronous : Bool) (repositoryUrl : String) (credentials : (String, String)) (envDeps : Map<String, Any>) :
  Container = Axiom "Make a container configured with its Vsync as asynchronous or not, built from source pulled from the given
  source control url, and provided the given environmental dependencies."

let attachDebugger (container : Container) = Axiom! "Attach debugger to code called inside the given container."

let call (mfn : MetaFunction) provider intent args : Vsync<Symbol> = mfn provider intent args
```



## Semantic Design for Unengine (a library for game programming without a monolithic game engine)

```
let Time = Axiom "The current simulation time."
let Input = Axiom "The current state of HID input."
let Address = Axiom "A series of names denoting a simulant in the hierarchy."
let Listener = Axiom "A generalized reference to a Listener<_>."
let Simulant = Axiom "A generalized reference to a Simulant<_, _, _, _, _>."
let RenderMsg = Axiom "A sum type representing the different render requests a simulant can send."
let IOMsg<MyUpdateMsg> =
  | CreateSimulant of ... | DestroySimulant of ...
  | CreateListener of ... | DestroyListener of ...
  | CreatePhysicsBody of (Address, PhysicsBodyUpdateMsg -> MyUpdateMsg, ...)
  | DestroyPhysicsBody of ...
  | PlaySound of ...
  | ...

let Listener<TheirUpdateMsg, MyUpdateMsg> =
  (Address : Address,
   Import : TheirUpdateMsg -> MyUpdateMsg)

let Simulant<Config, State, UpdateMsg> =
  (Name : String,
   Persistent : Bool,
   Init : Config -> Time -> (State, List<UpdateMsg>),
   Sense : State -> Time -> Input -> (State, List<UpdateMsg>),
   Update : State -> Time -> UpdateMsg -> (State, List<UpdateMsg>, List<IOMsg<UpdateMsg>>),
   Draw : State -> Time -> List<RenderMsg>,
   Listeners : List<Listener>,
   Children : List<Simulant>)
```