First Committee Meeting

Progress Report

Jason Balaci

McMaster University

Oct. 21^{st}, 2021

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Who am I?

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- I am **Jason Balaci**

Me, Camping in Killarney Prov. Park, Fall 2019

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- I am **Jason Balaci**
- Graduate of *McMaster University*, holding...
  - Hons. Actuarial and Financial Mathematics (B.Sc.)
  - Minor in Computer Science
- Currently pursuing a thesis-based Master's of Computer Science (M.Sc) at *McMaster University*, under the supervision of **Dr. Jacques Carette**.

Me, Camping in Killarney Prov. Park, Fall 2019

- I'm required to complete[1][2]:

[1] https://academiccalendars.romcmaster.ca/preview_program.php?catoid=45&poid=23470&returnto=9166

[2] http://www.cas.mcmaster.ca/cas/0files/reg_master_cs_2019a.pdf

Overview of Progression Towards C.S. M.Sc.

Course-related progression

- I'm required to complete[1,2]:
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- Together, the courses completed satisfies the "Courses Requirement" as mentioned in the academic calendar[1] and the "Regulations for the Computer Science M.Sc. Program" document[2].

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- Attended a thesis defence to learn about what to expect from a thesis defence (and learn about their research).

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- Attended a thesis defence to learn about what to expect from a thesis defence (and learn about their research).
- Supervisory committee is formed, and we are currently having our first supervisory committee meeting.
    - *Supervisor*: Dr. Jacques Carette
    - Dr. Spencer Smith
    - Dr. Wolfram Kahl

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What is Drasil?

Drasil...

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[Carette et al., 2021b][Yggdrasil - Wikipedia, 2021]

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- Drasil currently focuses on building research software, generating Software Requirement Specification documents (SRS) in both LaTeX and HTML (with MathJaX), code to solve a problem, README files, Makefiles, graphs, etc.

Drasil Case Studies

[1] https://jacquescarette.github.io/Drasil/#Sec:Examples

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  - **Solar Water Heating System (SWHS)** - Modelling of a solar water heating system with phase change material, predicting temperatures and change in heat energy of water and the PCM over time.

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Drasil Case Studies

- *cont.d*[1]:
  - **SWHS without Phase Change Material (NoPCM)** - Modelling of a solar water heating system without phase change material, predicting temperatures and change in heat energy of water and the PCM over time.

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  - **Slope Stability Analysis Program (SSP)** - Assessment of the safety of a slope (composed of rock and soil) subject to gravity, identifying the surface most likely to experience slip and an index of its relative stability (factor of safety).

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The Drasil website is also generated by Drasil!

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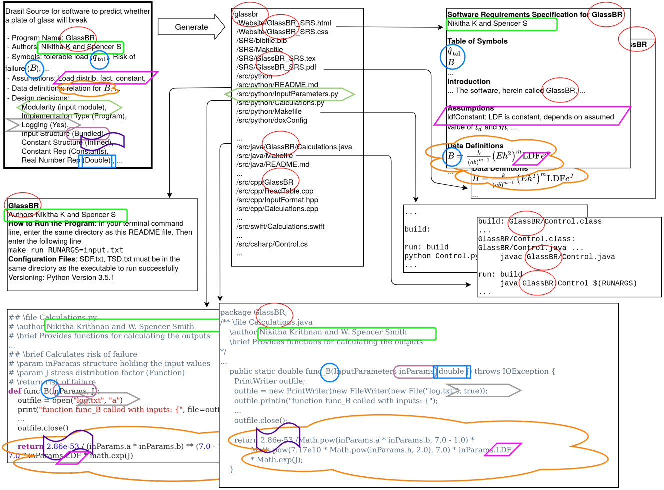
Taking a closer look at one of the examples: GlassBR

GlassBR Generates Code!



Knowledge flow from "knowledge-base"/source to artifacts, by Dr. Spencer Smith

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Generating view-only data (e.g., SRS documents) is considerably easier than generating artifacts that are "evaluated" in some way or another (e.g., compilation/interpretation/static analysis). These are largely different "printers".

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A few, notable, blocking problems:

- Confidently generating usable software artifacts without strong type information places significant stress on developers, resulting in a higher likelihood of bugs in artifacts.
- Existing "theories"/"*Models"[1] don't expose enough information. They must be enriched, so that we can better interact with, and understand them.

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Goal #1: Typed Expression Language

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- We want to ease developer cognitive load when writing expressions, as they will need to ensure their expressions are coherent, or else various problems (type, syntax, etc) can occur at runtime (of generated software artifacts).

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- Add extra functionality to existing expression languages safely, allowing for new data types to be introduced.
- Adding type information to expressions shouldn't be a burden!
- Decomposing/splitting vocabularies so that we can impose restrictions on allowed terms, while not causing problems for interoperability.

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    - Theories that rely on discussion of terms only found in ModelExpr may only have representational code generated if we have rich surrounding data (preferably also that generates said "ModelExpr"s, see goal #2).

Goal #1: Typed Expression Language

Current Progression

- Split core mathematical expression language (Expr) into 3 variants (Expr, ModelExpr, and CodeExpr)
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  - CodeExpr is a clone of Expr, with a few extra functionalities for GOOL.
  - Created a "typed tagless final" [Carette et al., 2009] smart constructor encoding for writing expressions in Expr, and/or ModelExpr.

Goal #1: Typed Expression Language

Current Progression

```haskell
offset' :: PExpr
offset' = sy landPos $- sy targPos

message :: PExpr
message = completeCase [case1, case2, case3]
  where case1 = (str "The target was hit.",        abs_ (sy offset $/ sy targPos) $< sy tol)
        case2 = (str "The projectile fell short.", sy offset $< exactDbl 0)
        case3 = (str "The projectile went long.",  sy offset $> exactDbl 0)

--
speed' :: PExpr
speed' = sy QP.iSpeed `addRe` (sy QP.constAccel `mulRe` sy time)

scalarPos' :: PExpr
scalarPos' = sy iPos `addRe` (sy QP.iSpeed `mulRe` sy time `addRe` half (sy QP.constAccel `mulRe` square (sy time)))
```

Polymorphic Expressions can become Exprs or ModelExprs

Goal #1: Typed Expression Language

Current Progression

```haskell
rectPosDerivEqn1, rectPosDerivEqn2, rectPosDerivEqn3 :: ModelExpr
rectPosDerivEqn1 = sy speed $= deriv (sy scalarPos) time
rectPosDerivEqn2 = defint (eqSymb scalarPos) (sy iPos) (sy scalarPos) (exactDbl 1) $=
                   defint (eqSymb time) (exactDbl 0) (sy time) (sy speed)
rectPosDerivEqn3 = defint (eqSymb scalarPos) (sy iPos) (sy scalarPos) (exactDbl 1) $=
                   defint (eqSymb time) (exactDbl 0) (sy time) (sy QP.iSpeed `addRe` (sy QP.constAccel `mulRe` sy time))
```

Derivation Expressions, using terms only available in ModelExpr

Goal #1: Typed Expression Language

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- Adjusting containers to allow for expressions with a type variable.

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- Adjusting containers to allow for expressions with a type variable.
- Adding the final type signatures, using Haskell GADT syntax.

Assume we have a general concept consisting of $y = m \cdot x + b$, and a natural description "The equation of a line, with a constant, b, and a dependent and independent variable, y and x, respectively.".

Goal #2: Theory Discrimination – "ModelKinds"

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- What if we want to change the symbols used? How do we know the “b” referred to in the equation is the same as the symbol “b” in the natural description?
- We’re ignoring the obvious information that this is the equation of a line, and that this is just an alternative “Definition”.

Goal #2: Theory Discrimination – "ModelKinds"

Problem Description, *cont.d*

- "RelationConcepts" were heavily used in both displaying expressions, and code generation. They are essentially "Relation"s ("Expr"s) with a natural language description of them.

Goal #2: Theory Discrimination – “ModelKinds”

Problem Description, *cont.d*

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- "RelationConcept"s don't contain enough information on their own to be a core component usable in general code generation.
- If the "shape" of the expressions are not uniform, then writing more "interpreters"/"views"/code generators for them required difficult pattern analysis. It's also not a total-conversion.

Goal #2: Theory Discrimination – "ModelKinds"

What makes up a "good" solution?

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- We should be able to easily add extra "ModelKind" variants.

Goal #2: Theory Discrimination – "ModelKinds"

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- Considerable number of "theories"/"*Models" have been restructured, but there are still many that are pending classification.
  - Most are best to be done once we have a typed expression language (so that we can better handle expressions that involve collections), and the rest are differential equation-related models (primarily Dong's domain).

Goal #2: Theory Discrimination – "ModelKinds"

Current Progression

```haskell
data QDefinition e where
  QD :: Express e => DefinedQuantityDict -> [UID] -> e -> QDefinition e
```

Current QDefinitions

```haskell
-- | 'DefiningExpr' are the data that make up a (quantity) definition, namely
--   the description, the defining (rhs) expression and the context domain(s).
--   These are meant to be 'alternate' but equivalent definitions for a single concept.
data DefiningExpr e = DefiningExpr {
  _deUid  :: UID,             -- ^ UID
  _cd     :: [UID],           -- ^ Concept domain
  _rvDesc :: Sentence,        -- ^ Defining description/statement
  _expr   :: Express e => e   -- ^ Defining expression
}
makeLenses ''DefiningExpr

-- | 'MultiDefn's are QDefinition factories, used for showing one or more ways we
--   can define a QDefinition.
data MultiDefn e = MultiDefn {
    _rUid  :: UID,                                       -- ^ UID
    _qd    :: QuantityDict,                              -- ^ Underlying quantity it defines
    _rDesc :: Sentence,                                  -- ^ Defining description/statement
    _rvs   :: Express e => NE.NonEmpty (DefiningExpr e) -- ^ All possible/omitted ways we can define the related quantity
}
makeLenses ''MultiDefn
```

Current MultiDefns

Goal #2: Theory Discrimination – "ModelKinds"

Current Progression

```haskell
-- | Models can be of different kinds:
--
--     * 'DEModel's represent differential equations as 'RelationConcept's
--     * 'EquationalConstraint's represent invariants that will hold in a system of equations.
--     * 'EquationalModel's represent quantities that are calculated via a single definition/'QDefinition'.
--     * 'EquationalRealm's represent MultiDefns; quantities that may be calculated using any one of many 'DefiningExpr's (e.g., 'x = A = ... = Z')
--     * 'FunctionalModel's represent quantity-resulting function definitions.
--     * 'OthModel's are placeholders for models. No new 'OthModel's should be created, they should be using one of the other kinds.
data ModelKinds e where
  DEModel              :: Express e => RelationConcept -> ModelKinds e
  EquationalConstraints :: Express e => ConstraintSet e -> ModelKinds e
  EquationalModel      :: Express e => QDefinition e   -> ModelKinds e
  EquationalRealm      :: Express e => MultiDefn e     -> ModelKinds e
  OthModel             :: Express e => RelationConcept -> ModelKinds e -- TODO: Remove (after having removed all instances of it).
```

Current ModelKinds

Goal #2: Theory Discrimination – "ModelKinds"

Current Progression

```haskell
-- | An instance model is a ModelKind that may have specific inputs, outputs, and output
-- constraints. It also has attributes like references, derivation, labels ('ShortName'), reference address, and notes.
data InstanceModel = IM { _mk       :: ModelKind Expr
                        , _imInputs :: Inputs
                        , _imOutput :: (Output, OutputConstraints)
                        , _rf       :: [DecRef]
                        , _deri     :: Maybe Derivation
                        ,  lb       :: ShortName
                        ,  ra       :: String
                        , _notes    :: [Sentence]
                        }
makeLenses ''InstanceModel
```

Current InstanceModel

Goal #2: Theory Discrimination – "ModelKinds"

Current Progression

```haskell
-- | A general definition is a 'ModelKind' that may have units, a derivation,
-- references (as 'DecRef's), a shortname, a reference address, and notes.
data GenDefn = GD { _mk     :: ModelKind ModelExpr
                  , gdUnit :: Maybe UnitDefn
                  , _deri   :: Maybe Derivation
                  , _rf     :: [DecRef]
                  , _sn     :: ShortName
                  , _ra     :: String -- RefAddr
                  , _notes  :: [Sentence]
                  }
makeLenses ''GenDefn
```

Current General Definitions

Goal #2: Theory Discrimination – “ModelKinds”

Current Progression

```haskell
data TheoryModel = TM
  { _mk     :: ModelKind ModelExpr
  , _vctx   :: [TheoryModel]
  , _spc    :: [SpaceDefn]
  , _quan   :: [QuantityDict]
  , _ops    :: [ConceptChunk]
  , _defq   :: [ModelQDef]
  , _invs   :: [ModelExpr]
  , _dfun   :: [ModelQDef]
  , _rf     :: [DecRef]
  ,  lb     :: ShortName
  ,  ra     :: String
  , _notes  :: [Sentence]
  }
makeLenses ''TheoryModel
```

Current TheoryModels

Goal #2: Theory Discrimination – "ModelKinds"

What are the next steps?

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- Understanding what kinds of needs we have for "collections", pushing this information back into the typed expression language (once that is fully typed), and then creating model containers for these models.

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- Cleaning up the existing implementation (removing the expression type parameter), and understanding where we want to go from here.
- A current proposal is pending further discussion in GitHub Issue #2853, potentially rebuilds ModelKinds to be extensible by using type constraints instead of GADTs.

Acknowledgements

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- Drasil has had significant development by past (and present) authors. Their public notes in the issue tracker, and their works (in particular, that of Brooks' thesis) have been especially helpful in learning about Drasil.

Fin.

Thank you!

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