Object-oriented Programming in Dependent Type Theory

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Old Version of Coalgebras: Codata Types

- Idea of Codata Types:

$$\begin{array}{l} \text{codata Stream} : \text{Set where} \\ \quad \text{cons} \quad : \quad \mathbb{N} \rightarrow \text{Stream} \rightarrow \text{Stream} \end{array}$$

- Same definition as inductive data type but we are allowed to have infinite chains of constructors

$$\text{cons}\ n_0\ (\text{cons}\ n_1\ (\text{cons}\ n_2\ \cdots))$$

Objects as Elements of Coalgebras

- Coalgebras are used for modelling various phenomena related **infinite sequences of computations**.
  - Correspond to **non-well-founded trees**.
  - Arise when dealing with **interactive programs**.
    - Interactive programs often don't terminate unless terminated by the user.
- Coalgebras arise as representations of **real numbers**.
  - Examples: **streams of digits**, **Cauchy sequences**.
  - In general approximations by finite values
- Coalgebraic programming is heavily used in **object-oriented Programming**.
  - See section on objects below.

Solution: Coalgebras Defined by Observations

- **Problem of codata types:** Non-normalisation and undecidability of equality.
- Instead we define define coalgebras by their observations.
  Tentative syntax

$$
\begin{array}{l}
\text{coalg Stream} : \text{Set where} \\
\quad \begin{array}{lcl}
\text{head} & : & \text{Stream} \to \mathbb{N} \\
\text{tail} & : & \text{Stream} \to \text{Stream}
\end{array}
\end{array}
$$

- Stream is the largest set of terms which allow arbitrary many applications of tail followed by head to obtain a natural numbers.
- From this one can develop a general model for coalgebras (see our paper [Set16]).
- Therefore no infinite expansion of streams:
  – for each expansion of a stream one needs one application of tail.

Syntax in Agda

- In Agda the record type has been reused for defining coalgebras:

```
record Stream (A : Set) : Set where
  coinductive
  field
    head  :  A
    tail  :  Stream A
```

Principle of Guarded Recursion

- Define

$$
\begin{array}{llllll}
f : A \to \mathsf{Stream} \\
\mathsf{head} & (f \ \ a) & = & \cdots & : & \mathbb{N} \\
\mathsf{tail} & (f \ \ a) & = & \cdots & : & \mathsf{Stream}
\end{array}
$$

  where

$$
\begin{array}{lllllll}
\mathsf{tail}\,(f \ a) & = & f \ a' & \text{for some} & a' & : & A \\
\text{or} \\
\mathsf{tail}\,(f \ a) & = & s' & \text{for some} & s' & : & \mathsf{Stream} \text{ given before}
\end{array}
$$

- **No** function can be applied to the corecursion hypothesis.
- Using sized types one can apply size preserving or size increasing functions to co-IH (Abel).
- Above is example of **copattern matching**.

Example

- Constant stream of $a, a, a, \ldots$

$$\begin{array}{lll} \text{const} : \{A : \text{Set}\} \to A \to \text{Stream} \;\; A & & \\ \text{head}\ (\text{const}\ a) & = & a \\ \text{tail}\ \ (\text{const}\ a) & = & \text{const}\ \ a \end{array}$$

- The increasing stream $n, n+1, n+2, \ldots$

$$\begin{array}{lll} \text{inc} : \mathbb{N} \to \text{Stream} \;\; \mathbb{N} & & \\ \text{head}\ (\text{inc}\ n) & = & n \\ \text{tail}\ \ (\text{inc}\ n) & = & \text{inc}\ (n+1) \end{array}$$

- Cons is **defined**:

$$\begin{array}{llll} \text{cons} & : X \to \text{Stream} \;\; X \to \text{Stream} \;\; X & & \\ \text{head} & (\text{cons}\ \ x\ l) & = & x \\ \text{tail} & (\text{cons}\ \ x\ l) & = & l \end{array}$$

Nested Pattern/Copattern Matching

- We can even define functions by a combination of pattern and copattern matching and nest those:
  The following defines the stream

$$\text{stutterDown}\ \ n\ n \;=\; n, n, n-1, n-1, \ldots 0, 0, n, n, n-1, n-1, \ldots$$

$$\begin{array}{ll}
\text{stutterDown} : \mathbb{N} \to \mathbb{N} \to \text{Stream}\ \mathbb{N} & \\
\text{head}\ (\text{stutterDown}\ n\ m) & = m \\
\text{head}\ (\text{tail}\ (\text{stutterDown}\ n\ m)) & = m \\
\text{tail}\ (\text{tail}\ (\text{stutterDown}\ n\ (\text{suc}\ m))) & = \text{stutterDown}\ n\ m \\
\text{tail}\ (\text{tail}\ (\text{stutterDown}\ n\ 0)) & = \text{stutterDown}\ n\ n
\end{array}$$

Hello World in Agda

We can develop IO programs based on coalgebras and get the following hello world program:

```
module helloWorld where

open import ConsoleLib

main : ConsoleProg
main = run (WriteString "Hello World")
```

Object-Oriented/Based Programming

- Object-oriented (OO) programming is currently main programming paradigm.
  - Means that the main programming paradigm is essentially **coalgebraic programming**.
- Good for bundling operations into one objects, hiding implementations and reuse of code.
- Here restriction to **object-based programming**.
  - Only notion of an object covered.
  - Steps towards full OO programming work in progress.
- Ultimate goal: use objects in order to **organise proofs** in a better way.

Example: cell in Java

```
class cell <A> {

    /* Instance Variable */
    A content;

    /* Constructor */
    cell (A s) { content = s; }

    /* Method put */
    public void put (A s) { content = s; }

    /* Method get */
    public A get () { return content; }
}
```

Modelling Methods as Objects

- The Type (interface) cell modelled as a coalgebra Cell.
- A method

$$B \ \mathrm{m} \ (A \ x)$$

  is modelled as observation

$$\mathsf{m} : \mathsf{Cell} \to \mathsf{A} \to \mathsf{B} \times \mathsf{Cell}$$

- Return type void is modelled as Unit (one element type).
- A constructor with argument A modelled as a function defined by guarded recursion

$$\mathsf{cell} : \mathsf{A} \to \mathsf{Cell}$$

Cell in Agda

```
record Cell (X : Set) : Set where
  coinductive
  field
    put : X    → ( Unit × Cell X )
    get : Unit → ( X    × Cell X )

cell : {X : Set} → X → Cell X
put (cell x) y = (unit , cell y)
get (cell x) _ = (x    , cell x)
```

Generic Version

An interface for an object consist of methods and the result type:

```
record Interface  :  Set₁ where
   field  Method  :  Set
          Result  :  Method → Set
```

An Object of an interface I has a method which for every method returns an element of the result type and the updated object:

```
record Object (I : Interface) : Set where
   coinductive
   field objectMethod : (m : Method I) → Result I m × Object I
```

Example: A Cell

A cell contains one element.
The methods allow to get its content and put a new value into the cell:

```
data CellMethod A : Set where
  get  :  CellMethod A
  put  :  A → CellMethod A

CellResult              :  ∀{A} → CellMethod A → Set
CellResult  {A} get     =  A
CellResult  (put _)     =  Unit

cellI                   :  (A : Set) → Interface
Method  (cellI A)       =  CellMethod A
Result  (cellI A) m     =  CellResult m
```

Definition of Cell

The cell object is defined as follows:

$$\begin{array}{l} \mathsf{Cell} : \mathsf{Set} \to \mathsf{Set} \\ \mathsf{Cell}\ A = \mathsf{Object}\ (\mathsf{cellI}\ A) \end{array}$$

$$\begin{array}{llll} \mathsf{cell} : \{A : \mathsf{Set}\} \to A \to \mathsf{Cell}\ A & & & \\ \mathsf{objectMethod}\ (\mathsf{cell}\ a)\ \mathsf{get} & = & (\ a & ,\ \mathsf{cell}\ a\ ) \\ \mathsf{objectMethod}\ (\mathsf{cell}\ a)\ (\mathsf{put}\ b) & = & (\ \mathsf{unit} & ,\ \mathsf{cell}\ b\ ) \end{array}$$

State Dependent Interface

$$
\begin{array}{l}
\text{record Interface}^{\mathrm{s}} : \text{Set}_1 \text{ where} \\
\quad \text{field} \\
\qquad \begin{array}{lcl}
\text{State}^{\mathrm{s}} & : & \text{Set} \\
\text{Method}^{\mathrm{s}} & : & \text{State}^{\mathrm{s}} \to \text{Set} \\
\text{Result}^{\mathrm{s}} & : & (s : \text{State}^{\mathrm{s}}) \to (m : \text{Method}^{\mathrm{s}}\ s) \to \text{Set} \\
\text{next}^{\mathrm{s}} & : & (s : \text{State}^{\mathrm{s}}) \to (m : \text{Method}^{\mathrm{s}}\ s) \to \text{Result}^{\mathrm{s}}\ s\ m \\
 & & \to \text{State}^{\mathrm{s}}
\end{array}
\end{array}
$$

State Dependent Object

Assuming I : Interface$^{\mathrm{s}}$ we define the set of state dependent objects:

record Object$^{\mathrm{s}}$ (I : Interface$^{\mathrm{s}}$) (s : State$^{\mathrm{s}}$ I) : Set where
coinductive
field
objectMethod : (m : Method$^{\mathrm{s}}$ I s)
$\to$ Σ[$r \in$ Result$^{\mathrm{s}}$ I s m] Object$^{\mathrm{s}}$ I (next$^{\mathrm{s}}$ I s m r)

Example Safe Stack

$$\text{StackState}^{\text{s}} = \mathbb{N}$$

$$\begin{array}{l}\text{data StackMethod}^{\text{s}}\ (A : \text{Set}) : \text{StackState}^{\text{s}} \to \text{Set where} \\ \quad \text{push} : \{n : \text{StackState}^{\text{s}}\} \to A \to \text{StackMethod}^{\text{s}}\ A\ n \\ \quad \text{pop} \ \ : \{n : \text{StackState}^{\text{s}}\} \to \text{StackMethod}^{\text{s}}\ A\ (\text{suc}\ n)\end{array}$$

$$\begin{array}{l}\text{StackResult}^{\text{s}} : (A : \text{Set}) \to (s : \text{StackState}^{\text{s}}) \to \text{StackMethod}^{\text{s}}\ A\ s \\ \qquad\qquad\qquad \to \text{Set} \\ \text{StackResult}^{\text{s}}\ A\ .n\ (\text{push}\ \{\ n\ \}\ x_1) \ = \text{Unit} \\ \text{StackResult}^{\text{s}}\ A\ (\text{suc}\ .n)\ \ (\text{pop}\ \{n\}\ ) = A\end{array}$$

$$\begin{array}{l}\text{n}^{\text{s}} : (A : \text{Set}) \to (s : \text{StackState}^{\text{s}}) \to (m : \text{StackMethod}^{\text{s}}\ A\ s) \\ \qquad \to (r : \text{StackResult}^{\text{s}}\ A\ s\ m) \to \text{StackState}^{\text{s}} \\ \text{n}^{\text{s}}\ A\ .n\ (\text{push}\ \{\ n\ \}\ x)\ \ r = \text{suc}\ n \\ \text{n}^{\text{s}}\ A\ (\text{suc}\ .n)\ (\text{pop}\ \ \{\ n\ \})\ r = n\end{array}$$

Safe Stack

$$
\begin{array}{llll}
\mathsf{StackInterface}^{\mathrm{s}} : (A : \mathsf{Set}) \to \mathsf{Interface}^{\mathrm{s}} & & & \\
\mathsf{State}^{\mathrm{s}} & (\mathsf{StackInterface}^{\mathrm{s}}\ A) & = & \mathsf{StackState}^{\mathrm{s}} \\
\mathsf{Method}^{\mathrm{s}} & (\mathsf{StackInterface}^{\mathrm{s}}\ A) & = & \mathsf{StackMethod}^{\mathrm{s}}\ A \\
\mathsf{Result}^{\mathrm{s}} & (\mathsf{StackInterface}^{\mathrm{s}}\ A) & = & \mathsf{StackResult}^{\mathrm{s}}\ A \\
\mathsf{next}^{\mathrm{s}} & (\mathsf{StackInterface}^{\mathrm{s}}\ A) & = & \mathsf{n}^{\mathrm{s}}\ A
\end{array}
$$

$$
\begin{array}{l}
\mathsf{stackO} : \forall\{E : \mathsf{Set}\}\ \{n : \mathbb{N}\}\ (v : \mathsf{Vec}\ E\ n) \\
\qquad \to \mathsf{Object}^{\mathrm{s}}\ (\mathsf{StackInterface}^{\mathrm{s}}\ E)\ n \\
\mathsf{objectMethod}\ (\mathsf{stackO}\ es)\ (\mathsf{push}\ e) = (\_\ ,\ \mathsf{stackO}\ (e :: es)) \\
\mathsf{objectMethod}\ (\mathsf{stackO}\ (e :: es))\ \mathsf{pop} = (e\ ,\ \mathsf{stackO}\ es)
\end{array}
$$

Example Fibonacci Stack

```
data FibState : Set where
    fib : ℕ → FibState
    val : ℕ → FibState
```

```
data FibStackEl : Set where
    _+·     : ℕ → FibStackEl
    ·+fib_  : ℕ → FibStackEl
```

```
FibStack : ℕ → Set
FibStack = Objectˢ (StackInterfaceˢ FibStackEl)
```

```
emptyFibStack : FibStack 0
emptyFibStack = stackO []
```

Reduce

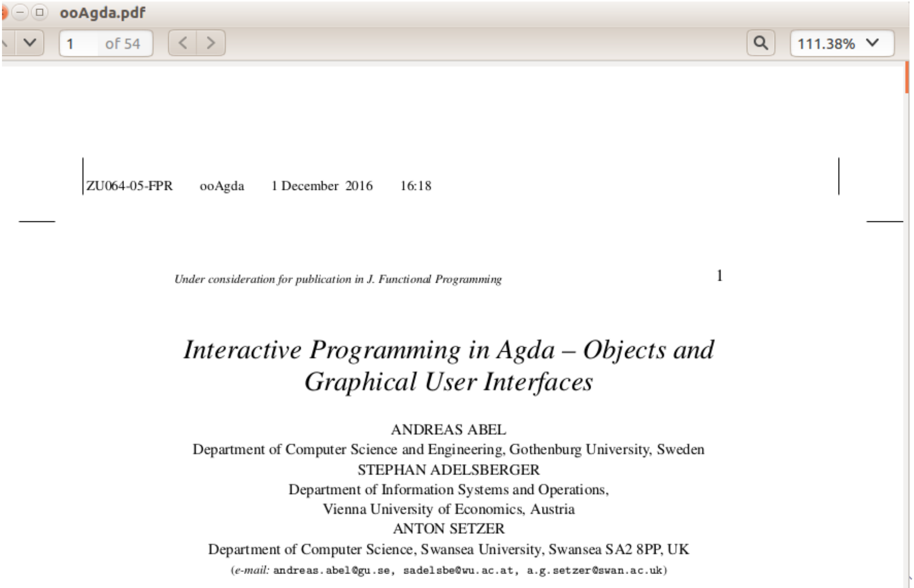
```
reduce : Stackmachine →  Stackmachine ⊎ ℕ
reduce (n , fib 0 , stack) = inj₁ (n , val 1 , stack)
reduce (n , fib 1 , stack) = inj₁ (n , val 1 , stack)
reduce (n , fib (suc (suc m)) , stack) =
   objectMethod stack (push (·+fib m))  ▷  λ { (_ , stack₁) →
   inj₁ ( suc n , fib (suc m) , stack₁)       }
reduce (0 , val m , _ ) = inj₂ m
reduce (suc n , val m , stack) =
   objectMethod stack pop  ▷            λ {  (k +· , stack₁) →
   inj₁ (n , val (k + m) , stack₁) ;
                                                (·+fib k , stack₁) →
   objectMethod stack₁ (push (m +·)) ▷ λ {(_ , stack₂) →
   inj₁ (suc n , fib k , stack₂) }  }
```

Fibonacci Function

```
{-# NON_TERMINATING #-}
iter : Stackmachine → ℕ
iter stack  with reduce stack
... | inj₁ s'  = iter s'
... | inj₂ m   = m

fibUsingStack : ℕ → ℕ
fibUsingStack n = iter (0 , fib n , emptyFibStack)
```

Paper to appear in JFP [AAS16a]



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Under consideration for publication in J. Functional Programming 1

Interactive Programming in Agda – Objects and Graphical User Interfaces

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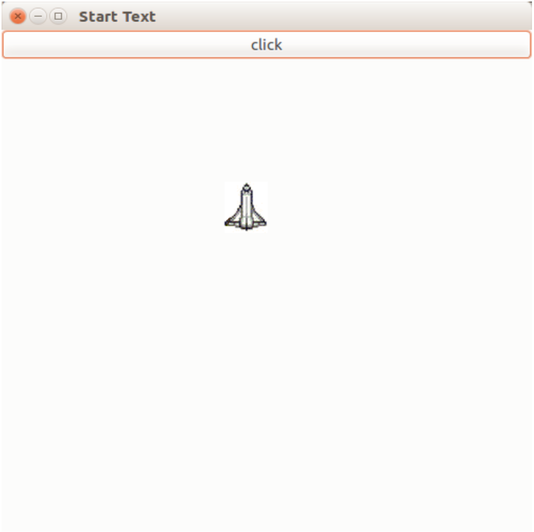
Results in [AAS16a]

- Development of GUIs in Agda.
  - Based on **server-side** programmings.
  - Use of **action listeners** which are part of an **object**
- Verification of laws of a safe and equivalences of implementations of stacks using bisimilarity.
- Library ooAgda on github [AAS16b].
- **Remark:** Library CSP-Agda for the process algebra CSP in Agda is now on github, see [IS17], article: [IS16].

SpaceShip Example



Dynamic Creation of Objects

- Idea is to create a set **Heap**, and pointers on the heap which dereference as objects.
- We have a state dependent object heap
  - depending on the size of the heap,
  - and methods for
    - dereferencing pointers,
    - updating pointers,
    - creating new pointers (which increases the size
- Currently working on linked and double linked lists built on the heap.
  - Goal is to create a proper queue.
  - Idea: Develop and verify the networking protocols such as the Chord protocol.

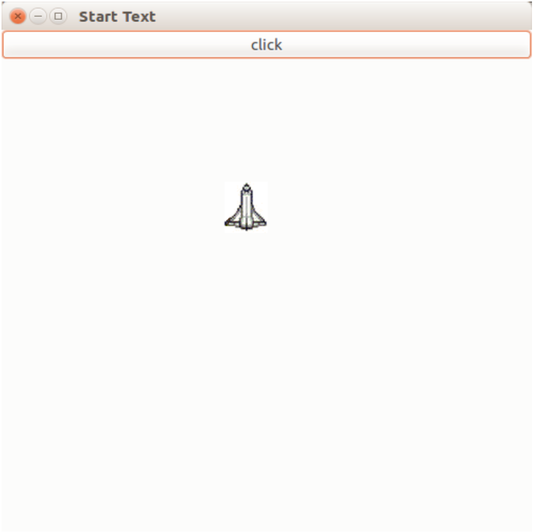
Current Challenges

- What is the right language?
  - At the moment in OO programs in Agda we need to introduce for every new instance of an object a new variable.
    - Can we write a library which hides these new variables?
    - Do we need new language constructs in Agda or (preferred) can we achieve this using the library?
- How to execute programs involving the heap efficiently.
  - At the moment heap is implemented as a list of heap elements.
  - Can we in a compiled version override this by calls to the "real" heap?
  - Do we obtain good performance of a queue?
  - Is it possible to write a true heap directly in Agda without overriding?

Conclusion

- Definition of **coinductive data types** (coalgebras) by their **observations**.
  - Use of **copattern** matching
- **Objects** as examples of coalgebras.
- **State dependent objects**.
- **Current work:** Developing of heap and dynamic creation of objects on the heap.

SpaceShip Example



Graphics Interface Level1

```
data GuiLev1Command : Set where
   makeFrame   :  GuiLev1Command
   makeButton  :  Frame  →  GuiLev1Command
   addButton   :  Frame  →  Button  →  GuiLev1Command
   drawBitmap  :  DC     →  Bitmap  →  Point → Bool
                  → GuiLev1Command
   repaint     :  Frame  →  GuiLev1Command

GuiLev1Response : GuiLev1Command → Set
GuiLev1Response  makeFrame       = Frame
GuiLev1Response (makeButton _)   = Button
GuiLev1Response  _               = Unit

GuiLev1Interface : IOInterface
Command  GuiLev1Interface  =  GuiLev1Command
Response GuiLev1Interface  =  GuiLev1Response
```

Graphics Level2 Commands

```
GuiLev2State : Set₁
GuiLev2State = VarList


data GuiLev2Command (s : GuiLev2State) : Set₁ where
  level1C           : GuiLev1Command → GuiLev2Command s
  createVar         : {A : Set} → A → GuiLev2Command s
  setButtonHandler  : Button
                      → List (prod s
                         → IO GuiLev1Interface ∞ (prod s))
                      → GuiLev2Command s
  setOnPaint        : Frame
                      → List (prod s → DC → Rect
                         → IO GuiLev1Interface ∞ (prod s))
                      → GuiLev2Command s
```

Graphics Level2 Response + Next

$$
\begin{array}{lll}
\text{GuiLev2Response} : & (s : \text{GuiLev2State}) \to \text{GuiLev2Command}\ s & \\
 & \to \text{Set} & \\
\text{GuiLev2Response}\ \_\ (\text{level1C}\ c) & = & \text{GuiLev1Response}\ c \\
\text{GuiLev2Response}\ \_\ (\text{createVar}\ \{A\}\ a) & = & \text{Var}\ A \\
\text{GuiLev2Response}\ \_\ \_ & = & \text{Unit}
\end{array}
$$

$$
\begin{array}{lll}
\multicolumn{3}{l}{\text{GuiLev2Next} : (s : \text{GuiLev2State}) \to (c : \text{GuiLev2Command}\ s)} \\
\multicolumn{3}{l}{\quad \to \text{GuiLev2Response}\ s\ c} \\
\multicolumn{3}{l}{\quad \to \text{GuiLev2State}} \\
\text{GuiLev2Next}\ s\ (\text{createVar}\ \{A\}\ a)\ \ var & = & \text{addVar}\ A\ var\ s \\
\text{GuiLev2Next}\ s\ \_\ \_ & = & s
\end{array}
$$

Graphics Level2 Interface

$$
\begin{array}{l}
\mathrm{GuiLev2Interface} : \mathrm{IOInterface}^{\mathrm{s}} \\
\begin{array}{lcl}
\mathrm{State}^{\mathrm{s}} \ \mathrm{GuiLev2Interface} & = & \mathrm{GuiLev2State} \\
\mathrm{Command}^{\mathrm{s}} \ \mathrm{GuiLev2Interface} & = & \mathrm{GuiLev2Command} \\
\mathrm{Response}^{\mathrm{s}} \ \mathrm{GuiLev2Interface} & = & \mathrm{GuiLev2Response} \\
\mathrm{next}^{\mathrm{s}} \ \mathrm{GuiLev2Interface} & = & \mathrm{GuiLev2Next}
\end{array}
\end{array}
$$

Action Handling Object

```
data ActionHandlerMethod : Set where
   onPaintM        : DC    →  Rect → ActionHandlerMethod
   moveSpaceShipM  : Frame →  ActionHandlerMethod
   callRepaintM    : Frame →  ActionHandlerMethod

ActionHandlerResult : ActionHandlerMethod  →  Set
ActionHandlerResult _ = Unit

ActionHandlerInterface : Interface
Method  ActionHandlerInterface  =  ActionHandlerMethod
Result  ActionHandlerInterface  =  ActionHandlerResult

ActionHandler : Set
ActionHandler =  IOObject GuiLev1Interface ActionHandlerInterface
```

Action Handling Object

```
actionHandler : ℤ → ActionHandler
method (actionHandler z) (onPaintM dc rect) =
   do∞  (drawBitmap dc ship (z , (+ 150)) true) λ _ →
   return∞  (unit , actionHandler z)
method (actionHandler z) (moveSpaceShipM fra) =
   return∞ (unit , actionHandler (z + (+ 20)))
method (actionHandler z) (callRepaintM fra) =
   do∞ (repaint fra)  λ _ →
   return∞ (unit , actionHandler z)

actionHandlerInit : ActionHandler
actionHandlerInit = actionHandler (+ 150)
```

Action Handlers

$$\text{onPaint} \;:\; \text{ActionHandler} \to \text{DC} \to \text{Rect} \to \text{IO GuiLev1Interface ActionHandler}$$
$$\text{onPaint}\; \mathit{obj}\; \mathit{dc}\; \mathit{rect} = \text{mapIO}\;\; \text{proj}_2\;\; (\text{method}\; \mathit{obj}\; (\text{onPaintM}\; \mathit{dc}\; \mathit{rect}))$$

$$\text{moveSpaceShip} : \text{Frame} \to \text{ActionHandler} \to \text{IO}\;\; \text{GuiLev1Interface ActionHandler}$$
$$\text{moveSpaceShip}\; \mathit{fra}\; \mathit{obj} \;=\; \text{mapIO}\;\; \text{proj}_2\;\; (\text{method}\; \mathit{obj}\; (\text{moveSpaceShipM}\; \mathit{fra}))$$

Action Handlers

$$\begin{aligned}\text{callRepaint} \ &: \ \text{Frame} \to \text{ActionHandler} \\ &\quad \to \text{IO GuiLev1Interface ActionHandler}\end{aligned}$$

$$\text{callRepaint}\ \mathit{fra}\ \mathit{obj} = \text{mapIO}\ \ \text{proj}_2\ (\text{method}\ \mathit{obj}\ (\text{callRepaintM}\ \mathit{fra}))$$

$$\begin{aligned}&\text{buttonHandler} : \text{Frame} \to \text{List (ActionHandler} \\ &\quad \to \text{IO GuiLev1Interface ActionHandler)} \\ &\text{buttonHandler}\ \mathit{fra} = \text{moveSpaceShip}\ \mathit{fra} :: [\ \text{callRepaint}\ \mathit{fra}\ ]\end{aligned}$$

Spaceship Program

```
program : IOˢ GuiLev2Interface (λ _ → Unit) []
program =  doˢ (level1C makeFrame)          λ fra →
           doˢ (level1C (makeButton fra))   λ bt →
           doˢ (level1C (addButton fra bt)) λ _ →
           doˢ (createVar actionHandlerInit) λ _ →
           doˢ (setButtonHandler bt  (moveSpaceShip fra
                                      :: [ callRepaint fra ])) λ _ →
           doˢ (setOnPaint fra [ onPaint  ])
           returnˢ

main : NativeIO Unit
main = start (translateLev2 program)
```

Bibliography I

Andreas Abel, Stephan Adelsberger, and Anton Setzer.
Interactive programming in Agda – objects and graphical user interfaces.
To appear in Journal of Functional Programming. Preprint available at http://www.cs.swan.ac.uk/~csetzer/articles/ooAgda.pdf, 2016.

Andreas Abel, Stephan Adelsberger, and Anton Setzer.
ooAgda.
Agda Library. Available from https://github.com/agda/ooAgda, 2016.

Bibliography II

Bashar Igried and Anton Setzer.
Programming with monadic CSP-style processes in dependent type theory.
In Proceedings of the 1st International Workshop on Type-Driven Development, TyDe 2016, pages 28–38, New York, NY, USA, 2016. ACM.
http://doi.acm.org/10.1145/2976022.2976032.

Bashar Igried and Anton Setzer.
CSP-Agda.
Agda library. Available at https://github.com/csetzer/cspagdaPublic, 2017.

Bibliography III

Anton Setzer.
Object-oriented programming in dependent type theory.
In Conference Proceedings of TFP 2006, 2006.
Available from http://www.cs.nott.ac.uk/~nhn/TFP2006/TFP2006-Programme.html and http://www.cs.swan.ac.uk/$\sim$csetzer/index.html.

Anton Setzer.
How to reason coinductively informally.
In Reinhard Kahle, Thomas Strahm, and Thomas Studer, editors, Advances in Proof Theory, pages 377–408. Springer, 2016.
Doi page http://link.springer.com/chapter/10.1007%2F978-3-319-29198-7_12, authors copy at http://www.cs.swan.ac.uk/~csetzer/articles/jaeger60Birthdaymain.pdf.