Declarative GUIs: Simple, Consistent, and Verified



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Verified Apps in Medical Domain

- Apps are increasingly used in safety critical applications, especially medical domain.
  - Example: assistance for prescription of medicines.
- Current assumption: responsibility is with the doctor.
  - Not sustainable.
- Testing not sufficient since coverage of all cases not possible for complex apps.
- Our approach: Create verified apps running directly in the Agda (theorem prover based on dependent types).
  - Avoids translation into a different language which can be source of new errors.
- Approach goes beyond finite state machines.
  - Data aware GUIs (arbitrary inputs).
  - Arbitrary many interactions between each GUI frame allowed.

Event Handlers as Dependent Types

- Common approach for designing graphical user interfaces is observer pattern based on action listeners.
- Two parts
  - Layout of GUI (called in our setting Frame).
  - Action listeners) handling all events (such as button clicks, mouse events) (called in our setting FrameObj).
- FrameObj
  - depends on the events of Frame.
  - can modify the elements in Frame.
- Therefore its type depends on Frame.

Event Handlers as Dependent Types

- When modifying Frame, therefore FrameObj needs to be adapted.
- Generic operations for modifying GUIs cannot be expressed without dependent types in a type correct way.
- Approaches to overcome this problem:
  - Use of dynamically typed programming languages.
  - Use of GUI builders which adapt user interfaces by program transformation resulting in machine generated code.
  - Our Proposal: Use of dependent types.

GUI Data Type Using Dependent Types

```
record GUI : Set where
  gui : Frame
  obj : FrameObj gui
```

State Dependent Objects

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

Assuming $(State, Method, Result, next) : \text{Interface}^s$

$$
\begin{array}{l}
\text{record IOObject}^s\ (s : State) : \text{Set where} \\
\quad \text{coinductive} \\
\quad \text{method} : \\
\qquad (m : Method\ s) \to \text{IO}\ (\Sigma[\ r \in Result\ s\ m\ ]\ \text{IOObject}^s\ (next\ s\ m\ r))
\end{array}
$$

GUIInterface

$$\text{GUIState} = \text{Frame}$$

$$\begin{aligned}\text{GUIElMethod}\ gui = {} & \text{Fin}\ (\text{guiEl2NrButtons frameCmpStruc frame}\ gui) \\ & \times\ \text{Tuple String} \\ & \quad (\text{guiEl2NrTextboxes frameCmpStruc frame}\ gui)\end{aligned}$$

$$\text{GUIElResult}\ gui\ m = \text{Frame}$$

$$\text{nextGUI}\ gui\ m\ r = r$$

$$\begin{aligned}&\text{GUIInterface} : \text{Interface}^{s} \\ &\text{GUIInterface}\ .\text{State}^{s} = \text{GUIState} \\ &\text{GUIInterface}\ .\text{Method}^{s} = \text{GUIElMethod} \\ &\text{GUIInterface}\ .\text{Result}^{s} = \text{GUIElResult} \\ &\text{GUIInterface}\ .\text{next}^{s} = \text{nextGUI}\end{aligned}$$

GUI Data

$$\mathsf{FrameObj} : \mathsf{Frame} \to \mathsf{Set}$$
$$\mathsf{FrameObj}\ gui = \mathsf{IOObject}^{\mathsf{s}}\ \mathsf{GUIInterface}\ gui$$

Used in the definition from above

```
record GUI : Set where
  gui : Frame
  obj : FrameObj gui
```

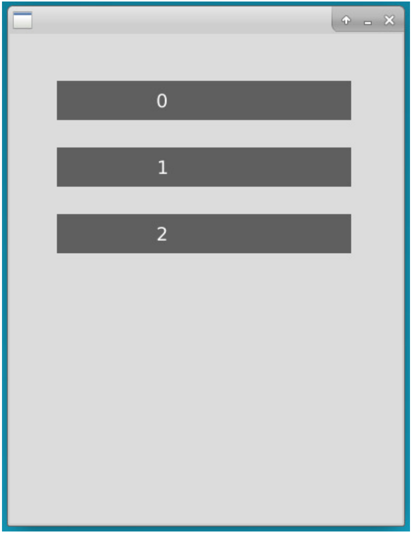
Example Infinite Buttons

$$
\begin{aligned}
&\mathrm{nFrame} : (n : \mathbb{N}) \to \mathrm{Frame} \\
&\mathrm{nFrame}\ 0 \qquad\quad = \mathrm{emptyFrame} \\
&\mathrm{nFrame}\ (\mathrm{suc}\ n) = \mathrm{addButton}\ (\mathrm{show}\ n)\ (\mathrm{nFrame}\ n)
\end{aligned}
$$

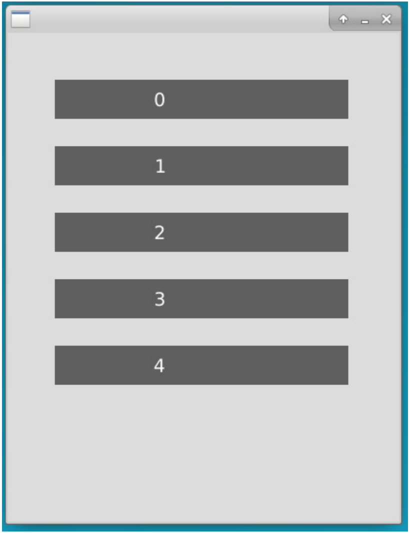
Object defined by copattern matching:

$$
\begin{aligned}
&\mathrm{infiniteBtns} : \forall\{i\} \to (n : \mathbb{N}) \to \mathrm{GUI}\ \{i\} \\
&\mathrm{infiniteBtns}\ n\ .\mathrm{gui} = \mathrm{nFrame}\ n \\
&\mathrm{infiniteBtns}\ 0\ .\mathrm{obj}\ .\mathrm{method}\ () \\
&\mathrm{infiniteBtns}\ (\mathrm{suc}\ n)\ .\mathrm{obj}\ .\mathrm{method}\ (m\ ,\ \_) = \\
&\quad \mathrm{returnGUI}\ (\mathrm{infiniteBtns}\ (n + \mathrm{finTo}\mathbb{N}\ m))
\end{aligned}
$$

Example Infinite Buttons



Example Infinite Buttons



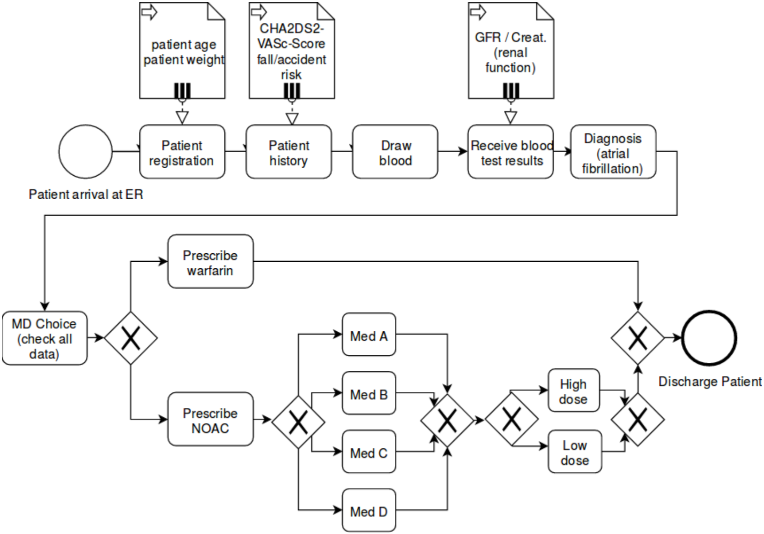
Business Processes

```
data BusinessModel : Set where
  terminate : String → BusinessModel
  xor       : List (String × BusinessModel)
              → BusinessModel
  input     : {n : ℕ} → Tuple String n
              → (Tuple String n → BusinessModel)
              → BusinessModel
  simple    : String → BusinessModel → BusinessModel

businessModel2Gui : BusinessModel → GUI
```

Screenshot

Medical Example



Model of Medical Process

```
discharge          = terminate "Discharge Patient"
lowdoseSelection   = simple "Low Dose"  discharge
highdoseSelection  = simple "High Dose" discharge
```

```
doseSelectionA : WghtCat → BusinessModel
doseSelectionA ≤60 = lowdoseSelection
doseSelectionA >60 = highdoseSelection
```

Model of Medical Process

```
bloodTestRes : FallRisk → AgeCat → WghtCat
                → BusinessModel
bloodTestRes f a w =
  input "Enter Bloodtest Result" λ str →
  diagnosis f (str2RenalCat str ) a w
```

Verification States of the GUI

```
data MethodStarted (g : GUI) : Set where
  notStarted : MethodStarted g
  started : (m : GUIMethod g)
            (pr : IO consoleI ∞ GUI) → MethodStarted g

data State : Set where
  state : (g : GUI) → MethodStarted g → State

Cmd : State → Set
Cmd (state g notStarted)                = GUIMethod g
Cmd (state g (started m (exec' c f)))  = IOResponse c
Cmd (state g (started m (return' a)))  = ⊤

guiNext : (g : State) → Cmd g → State
```

State Reached after Inputs

```
stateAfterBloodTest :
  (strAge strWght strFallR strScore strBlood : String)
  → State
stateAfterBloodTest strAge strWght strFallR strScore strBlood
  = guiNexts patientRegistrationState
              (nilCmd
                 ⋙ textboxInput2 strAge strWght
                 ⋙ textboxInput2 strFallR strScore
                 ⋙ btnClick
                 ⋙ textboxInput   strBlood)
```

Theorem 1

```
theoremWarfarin :
  (strAge strWght strFallR strScore strBlood : String)
   → str2RenalCat strBlood ≡ <25
   → stateAfterBloodTest strAge strWght strFallR
                         strScore strBlood
     -eventually-> warfarinState
```

Theorem 2

```
theoremNoLowDosisWeight>60 :
  (strAge strWght strFallR strScore strBlood : String)
  → str2WghtCat strWght ≡ >60
  → (w' : WghtCat)
  → stateAfterBloodTest strAge strWght strFallR
       strScore strBlood
     -gui-> NOACSelectionAState w'
  → (s : State)
  → NOACSelectionAState w' -gui-> s
  → ¬ (s ≡ lowdoseSelectionState)
```

Conclusion

- Event handlers depend on the frame, therefore are dependently typed.
- Event handler modelled by a state dependent object.
- More complex GUIs modelled by using a simple declarative data type for Business Processes.
- Model given by
  - States = States of the GUI
  - Transitions = GUI responses and IO events.

Conclusion

- Proof of correctness of GUIs.
- In medical domain
  - Conditions demanded originate from clinical studies which give negative results excluding certain medications and doses.
  - Programers write a program in a positive way which determines prescriptions.
  - Verification connects the two by showing that the program written by the user fulfils the conditions demanded by medicine.
- Program constantly changes in response to demands and changes of medicine.
- Declarative approach and dependent types support rapid adaption of program and verification.

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