Iterative Functional Reactive Programming with the Nu Game Engine

An Informal Experience Report

NOTE: This is an entirely informal 'paper', originally targeted for a simple post on a forum of http://lambda-the-ultimate.org, but due to my inability to achieve a readable formatting with the tools of said forum, is made available via this PDF.

So, I have this purely functional game engine in F# - https://github.com/bryanedds/FPWorks

For readers who wish to build some familiarity with the system before reading this admittedly terse description, please look here for Nu's high-level documentation - https://github.com/bryanedds/FPWorks/blob/master/Nu/Documentation/Nu%20Game%20Engine.pdf?raw=true

It certainly qualifies as 'functional reactive' in that -

1) it is reactive in that it uses user-defined events to derive new game states.
2) it is functional in that is uses pure functions everywhere, even in the event system.

However, I cannot describe it as the typical first-order or higher-order FRP system since it uses neither continuous nor discrete functions explicitly parameterized with time. Instead it uses a classically-iterative approach to advancing game states that is akin to the imperative tick-based style, but implemented with pure functions.

Thus, I gave it the name of 'Iterative FRP'. It's a half-way step between classic imperative game programming and first / higher-order FRP systems. There are plusses and minuses to using this 'Iterative FRP' style -

In the plus column -

1) it's perfectly straight-forward to implement nearly any arbitrary game algorithm without worrying about things like space or time leaks, or having to invoke higher-ordered forms of expression.
2) end-users don't need to understand new forms of expression beyond primitive functional expressions to encode their game logic. No lifting required!
3) it has a level of pluggability, data-drivenness, and serializability that are extremely difficult to pull off in FO/HOFRP systems.
4) none of its design is the subject of open research questions, and is therefore simple enough for non-PhD's to understand as well as complete in its implementation.

In the minus column -

1) its API is consequently large and there are multiple levels of abstraction at which you must choose to work, and consequently traverse.
2) there are no single, abstract means of composition for accomplishing disparate tasks across the API.
3) its available forms of expression are consequently not as high-level as FO/HOFRP systems, and the user can become bogged down in oft-irrelevant details like low-level state-transformations and navigating the rather proliferated data structures of the engine.
4) because the API is so data-driven, the world's simulants cannot be accessed without first retrieving them via their addresses.

To expand on point 4, addresses are a strongly-typed data structure parsed from a slash-delimited string of names. Addresses describe a simulant's 'location' in the world. Having to access each simulant through its address adds an additional layer of indirection that can be somewhat cumbersome, especially to imperative game developers who are used to having everything at the reach of a simple pointer indirection, which is then modifiable in-place.

Despite these minuses, I currently conclude IFRP is appropriate for such a general-purpose game engine because -

1) a general-purpose game engine is, by definition, not a DSL, but rather an API that, due to its generality, actually exposes *multiple* DSLs as well as the glue needed to combine them.
2) from my experience, games, and game technology in general, refuse to conform to any single system of thought, often demanding certain features be implemented with escape-hatch approaches like mutation in order to be efficient, or with lower-level forms of functional expression for flexibility.
3) just because the default means of expression is not as abstract as that of FO/HOFRP systems, it does not mean there are no available ways to 'climb into' more abstract forms of expression.

To expand on point 3, here are some of the higher forms of expression provided by the API -

Here we have an expression form called an 'observation' that allows expressive combinations and transformations of events like so -

```
let observation =
    observe (ClickEventAddress ->>- hudHaltAddress) address |>
    filter isSelected |>
    sum TickEventAddress |>
    until (DeselectEventAddress ->>- address)
```

This affords us the ability to treat events like first-class collections.

Here we have an expression form called a 'chain'. A chain is a monad that allows a procedural-style expression to span 0 or more events while also taking the world as an implicit state -

```
let chain = chain {
    do! updateEntity (Entity.setActivityState <| Action newActionDescriptor) characterAddress
    do! during
            (fun world ->
                let activityState = World.getEntityBy Entity.getActivityState characterAddress world
                ActivityState.isActing activityState) ^^
            chain {
                do! update ^^ fun world ->
                    let actionDescriptor =
                        match World.getEntityBy Entity.getActivityState characterAddress world  with
                        | Action actionDescriptor -> actionDescriptor
                        | _ -> failwithumf ()
                    let world = updateCharacterByAction actionDescriptor characterAddress world
                    runCharacterReaction actionDescriptor characterAddress address world
                do! pass }} // waits for next event, discarding its value
```

We also have the ability to compose chains overs observations like so -

```
let observation = observe TickEventAddress characterAddress |> until (DeselectEventAddress ->>- address)
let world = snd <| runAssumingCascade chain observation world
```

Also, instead of transforming the world directly, we have a large set of world-level functions that can operate on its sub-structures like so -

```
let world = World.updateEntity (Entity.setEnabled false) buttonAddress world
```

- as opposed to the more 'manual' way of updating a simulant in the world -

```
let button = World.getEntity buttonAddress world
let button = Entity.setEnabled (not button.Enabled) button
let world = World.setEntity button buttonAddress world
```

Additionally, we can use lenses to form operations over user-defined portions of the world like so -

```
let lens = World.lensEntities EntityAddresses @-> World.lensScreen ScreenAddress @-> World.lens
let world = World.updateLensed (fun (entities, (screen, world)) -> (f entities, (g screen, h world))) lens world
```

And of course, there are similar lensing combinators available when working at the level of 'chains'.

Finally, there is a means to declaratively forward the changing value of a simulant's field to that of another -

```
let world =
    world |>
        (BobAddress, Entity.getVisible) *--> (JimAddress, Entity.setVisible) |>
        (JimAddress, Entity.getVisible) /--> (BobAddress, not >> Entity.setVisible)
```

Here, ***-->** denotes the forwarding of the value of Bob's Visible field to Jim's Visible field. To throw a monkey-wrench into the declaration, **/-->** is used to in turn forward the value of Jim's Visible field back to Bob's Visible field, albeit **not**'d and with cycle-breaking so that the circularity of this expression is broken appropriately. A contrived example, but illustrative of the API's expressiveness.

So, depending on the nature of the game behavior you want to implement, the API provides enough surface area to do things at multiple points of a spectrum of efficiency and flexibility. But there is a down-side to an API with such a large surface area... With multiple expression forms and levels of abstractions at which to operate, the learning curve is regrettably steepened. However, I have yet to think of a way to drastically simplify the API without losing a portion of flexibility that games demand.

Even with functional programming, and even assuming my approach was optimal for the given point in my targeted design space, game engine design remains fundamentally difficult and peppered with compromise.