Distributed Systems Extensions for the Dunai FRP Library

https://github.com/jgotoh/distributed-frp-dunai

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Distributed Systems

According to Andrew S. Tanenbaum and Maarten Van Steen[TS07]:

> *A distributed system is a collection of independent computers that appears to its users as a single coherent system.*

- collaborating autonomous computers
- appear as one unit
- Multiplayer games: playing together in the same virtual world

Functional Reactive Programming

- Paradigm for implementing hybrid systems [Hud+02]
- Values that change over continous time: Signals

```
type Signal a = Time -> a
```

- Discrete Signals: Events
- Arrowized FRP: Signal Functions

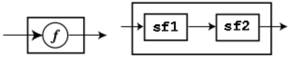
```
type SF a b = Signal a -> Signal b
```

  - SFs are Arrows: `Arr a b` [Hug00]
  - primitives and combinators
  - `sf >>> sf1 &&& sf2`
  - implicit Signals to avoid Space-Time Leaks
- FRP program: composition of a set of signals into one composite signal

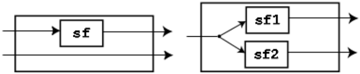
[NCP02]

Functional Reactive Programming

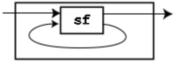
- `arr :: (a -> b) -> SF a b`
- `(>>>) :: SF a b -> SF b c -> SF a c`
- `first :: SF a b -> SF (a,c) (b,c)`
- `(&&&) :: SF a b -> SF a c -> SF a (b,c)`
- `loop :: SF (a,c) (b,c) -> SF a b`



(a) `arr f` (b) `sf1 >>> sf2`



(c) `first sf` (d) `sf1 &&& sf2`



(e) `loop sf`

Dunai

- Parametrized SFs with monads [Dom18]

```haskell
newtype MSF m a b
```

- `f :: Monad m =>m a`
- tries to subsume all FRP libraries
- Computation in a context with a result value of type a
- new primitive
  `arrM :: Monad m =>(a -> m b) -> MSF m a b`
- BearRiver is the successor of Yampa implemented using Dunai
  - `type ClockInfo m = ReaderT DTime m`
  - `type SF m = MSF (ClockInfo m)`

Distributed Systems Extensions for the Dunai FRP Library

Implementation of a library

- facilitate integration of autonomous machines running FRP into a single coherent system
- Communication via Client/ Server architecture
- Synchronisation of FRP states to migitate impact of network
- Clients send CommandPackets (input)
- Servers send UpdatePackets (state) [Val19]

Cloud Haskell

- distributed computing framework inspired by Erlang [AVW93], designed by Epstein, Black and Peyton Jones in 2011 [EBP11]
- processes communicate via messages
- as opposed to shared data
- implemented in set of packages called distributed-process [CWV18]
- agnostic to transport layer (TCP, UDP, ...)
- built-in support for Client/ Server

Processes and Nodes

- Processes
    - Erlang: virtual machines that evaluate Erlang functions [Arm07, p. 141]
    - Haskell: computations in the Process Monad
    - identified by unique process identifiers
    - lightweight creation, destruction and low scheduling overhead
- . . . running on Nodes
    - runtime system executing Erlang/ Haskell code
    - able to communicate with other Nodes
    - identifiable by a unique NodeId

Processes and Nodes

- Erlang: `Pid = spawn(Fun)`
- Haskell:

  `spawn :: NodeId -> Closure (Process()) -> Process ProcessId`

Messages

- Messages
- Erlang: send asynchronously: `Pid ! Message`
- Cloud Haskell: message consists of binary data and type representation

```
send :: Serializable a =>ProcessId -> a -> Process ()
class (Binary a, Typeable a) =>Serializable a
instance (Binary a, Typeable a) =>Serializable a
```

- siehe `distributed-paddles/GameState.hs`

Pattern Matching on incoming messages

Erlang:

```
math() ->
  receive
    {add, Pid, Num1, Num2} ->
      Pid ! Num1 + Num2;
    {divide, Pid, Num1, Num2} when Num2 != 0 ->
      Pid ! Num1 / Num2;
    {divide, Pid, _, _} ->
      Pid ! div_by_zero
  end,
  math().
```

Pattern Matching on incoming messages

Cloud Haskell:

```
data Add = Add ProcessId Double Double
data Divide = Divide ProcessId Double Double
data DivByZero = DivByZero
% Serializable instances are omitted
math :: Process ()
math =
  receiveWait
    [ match (\(Add pid num1 num2) ->
          send pid (num1 + num2)),
      matchIf (\(Divide _ _ num2) -> num2 /= 0)
          (\(Divide pid num1 num2) ->
              send pid (num1 / num2)),
      match (\(Divide pid _ _) ->
          send pid DivByZero) ]
  >> math
```

Typed Channels

- exclusive to Cloud Haskell
- uses Haskell's static type system
- ensures only messages of a specific type are sent to a process
- `type Channel a = (SendPort a, ReceivePort a)`

```
newChan :: Serializable a =>
    Process (SendPort a, ReceivePort a)
receiveChan :: Serializable a =>
    ReceivePort a -> Process a
sendChan :: Serializable a =>
    SendPort a -> a -> Process ()
mergePortsBiased :: Serializable a =>
    [ReceivePort a] -> Process (ReceivePort a)
mergePortsRR:: Serializable a =>
    [ ReceivePort a] -> Process (ReceivePort a)
```

Fault Tolerance

- Processes can be observed whether they terminate unexpectedly and expectedly
- monitor (unidirectional)
  - Erlang: `MonitorRef = erlang:monitor(process, Pid2)`
  - Haskell: `monitor :: ProcessId -> Process MonitorRef`
- link (bidirectional)
  - Erlang: `link(Pid2)`
  - Haskell: `link :: ProcessId -> Process ()`
- monitoring/ linking of Nodes and Channels is also possible

Dynamic Code Update

- Erlang: compiled to bytecode, run by interpreter
- Haskell: compiled to machine code, run by OS

```
-module(m).
-export([loop/0]).

loop() ->
  receive
    code_switch ->
      m:loop();
    Msg ->
      ...
      loop()
  end.
```

Implementation

- Network communication via Cloud Haskell (Process monad)
- Dunai runs in IO
- Cloud Haskell's messaging system only works in context of Process
- Dunai and Cloud Haskell need to communicate (UpdatePackets, Commandpackets)
- shared data structures are necessary: STM[Har+08]
    - lockfree synchronisation via revertible transactions

Main Loop

- Dunai: `reactimate :: MSF m () () -> m ()` [Dom18]
- BearRiver: [Dom18]

```
reactimate :: Monad m
=> m a                                   -- initial sense
-> (Bool -> m (DTime, Maybe a))  -- sense
-> (Bool -> b -> m Bool)           -- actuate
-> SF Identity a b
m ()
```

Main Loop

- reactimateClient (simplified):

```
reactimateClient :: Monad m
=> m (DTime, Maybe a) -- sense
-> (b -> m()) -- actuate
-> SF Identity (a, Maybe netin) b -- pure Signal Functions
-> m (Maybe netin) -- read UpdatePackets
-> ((DTime, Maybe a) -> m ()) -- send CommandPackets
-> m ()
```

- reactimateServer (simplified):

```
reactimateServer :: Monad m
=> m (DTime, Maybe a) -- sense
-> (b -> m()) -- actuate
-> SF Identity (a, Maybe netin) b -- pure Signal Functions
-> m (Maybe netin) -- read CommandPackets
-> (b -> m ()) -- send UpdatePackets
-> m ()
```

Next steps

- Synchronisation
    - Clock Synchronisation
    - State Synchronisation
        - Dead Reckoning
        - Error correction (Time Warp)

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