# The New Cloud Haskell

Duncan Coutts and Edsko de Vries

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The Haskell Consultants

# This talk...

What I want to talk about today...

- Very quick recap on Cloud Haskell
- The cool new stuff
  - details of the new implementation
  - message semantics
  - current status

Sorry, not a tutorial
(but come to the Haskell Exchange in London next month!)

# Cloud Haskell recap

# Cloud Haskell

What's it all about?

- Slogan could be “Erlang for Haskell” (as a library)
- Concurrent **distributed** programming in Haskell
- A programming model + an implementation

# Cloud Haskell

What's the point?

- To let you program a cluster as a whole,
- or a data centre,
- or a bunch of VMs rented from Azure / Amazon / ...
  (hence the "Cloud" marketing buzzword)

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**Key idea**

Program the cluster as a whole, not individual nodes

# Other people's good ideas

Papers

- Jeff Epstein, Andrew Black and Simon Peyton Jones, *Towards Haskell in the Cloud*, Haskell Symposium 2011
- Jeff Epstein, *Functional programming for the data centre*, MPhil thesis, 2011

Prototype

- `remote` package by Jeff Epstein

# Programming model

- Explicit concurrency
- Lightweight processes
- No state shared between processes
- Asynchronous message passing

Some people call this the “actor model”

# The Cloud Haskell design

Basic approach

- Design is implementable as a library
  - minimal language and RTS changes
  - e.g. no distributed `MVar` as in GdH
- If in doubt, do it the way Erlang does it

(Other distributed middleware designs are also possible)

# The core API

```
instance Monad Process
instance MonadIO Process

data ProcessId
data NodeId

class (Typeable a, Binary a) => Serializable a

send   :: Serializable a => ProcessId -> a -> Process ()
expect :: Serializable a => Process a

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

getSelfPid  :: Process ProcessId
getSelfNode :: Process NodeId
```

# Error handling style

Errors are everywhere in distributed programming

Cloud Haskell steals Erlang's solution

- Let processes fail
  - communication loss counts as failure
- Notify interested processes
  - often they just fail too (linked processes)
  - common pattern is to monitor and restart

```
link    :: ProcessId → Process ()
monitor :: ProcessId → Process MonitorRef
```

# What we’ve been up to...

# A new implementation

Simon PJ asked us to start work on a new implementation...

Initial goals

- Same public API (more or less)
- Robust implementation
- Flexible implementation

Interesting problems we ran into

- The need for semantics (!)
- Network disconnect and reconnect

# The need for flexibility

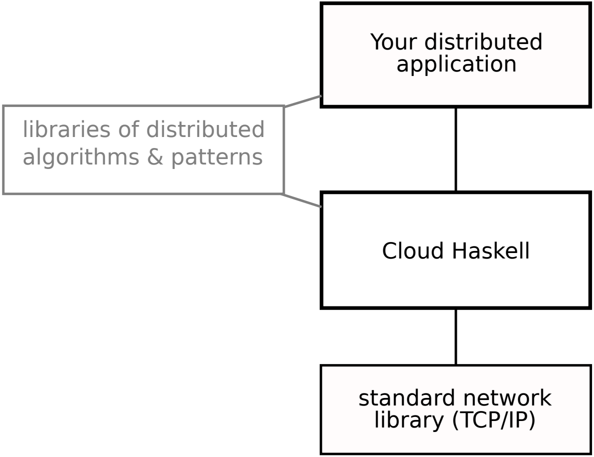
| Variation between use cases | Examples |
| --- | --- |
| ▸ Network data transport layer (hardware and protocol) | IP<br>exotic non-IP HPC networks<br>shared memory or local pipes |
| ▸ How to start your executable on each machine | remote login via ssh<br>cloud service API<br>cluster job scheduler |
| ▸ How to configure each node | via ssh from master node<br>config files, env vars, string and glue<br>distributed via cluster job scheduler |
| ▸ How to find initial peers or all peers | discover dynamically on LAN<br>known from config<br>cluster job scheduler<br>peers created in new VMs |

# The new implementation

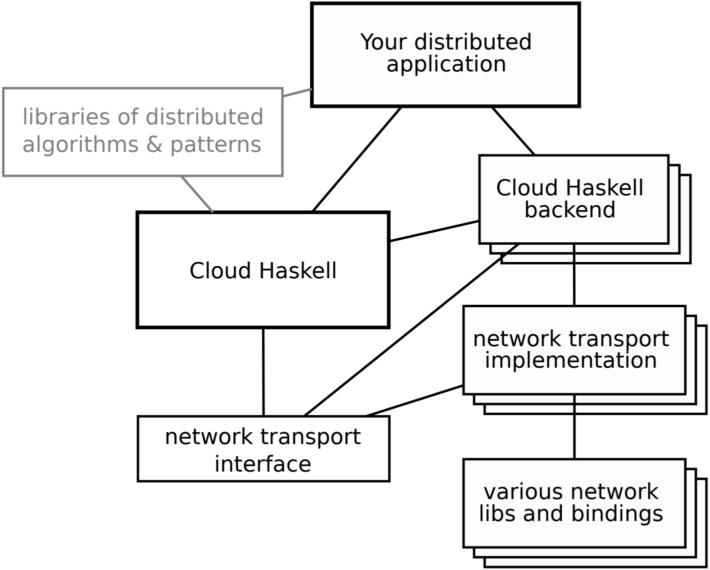
Key differences with the prototype implementation

- Swappable network transport layer
- Multiple Cloud Haskell backends to handle
  - selection of transport implementation
  - initialisation
  - configuration
  - peer discovery / creation
- More precisely specified semantics
  - message passing
  - node disconnect and reconnect

# Existing prototype design



# New internal design



# Network transport layer

Interface between network layer and Process layer

- Allows different network implementations
- Clarifies internal design of Cloud Haskell

Design considerations

- Meet needs of Cloud Haskell
- Be reusable in other projects if possible
- Allow many implementations with common semantics
- Allow high performance (latency)
- Allow high scalability (big clusters)

# Network transport layer

Key features

- heavyweight endpoints
- bundle of many lightweight connections between endpoints
- connections are
  - message oriented (not stream)
  - reliable and ordered (like TCP)
  - unidirectional
- single shared receive queue on each endpoint
  - all incoming messages from all connections
  - errors and other events
- clear network failure behaviour
  - explicit reporting of failures
  - bundles fail as a whole, not individual connections

# Network transport layer

Implementations

- TCP/IP
  - multiplexes lightweight connections over a single heavyweight TCP connection between endpoints
- Unix pipes (in progress)
- CCI (in progress)
  (CCI is an HPC networking lib supporting infiniband etc)

Also possible

- Shared memory
- SSH
- UDP
- TCP with SSL/TLS

The TCP implementation is already being used in projects other than Cloud Haskell

# Process layer outline

- Cloud Haskell node manages a set of processes
  - transport Endpoint per node
- Each Process runs in a Haskell thread
  - has a queue for incoming messages
- A lightweight transport Connection per pair of communicating processes
- A thread per node to reveive events
  - dispatches messges to per-process message queues
  - passes messages and notifications to the node controller
  - handles network error events (like peer node disconnect)
- A thread per node as the “node controller”
  - responsible for spawning, linking and monitoring
  - also manages a process registry (named processes)
- Other per-node service processes
  - currently just a logger

# Cloud Haskell backends

"SimpleLocalnet" backend

- simple backend to get started quickly
- no configuration
- uses the TCP transport
- node discovery using local UDP multicast

# Cloud Haskell backends

Windows Azure backend

- uses Linux VMs
- uses the TCP transport between the VMs
- initialise with Azure account and SSL certificates
- Support for:
  - VM enumeration
  - copying binaries to VMs
  - spawn nodes on VMs
- special API required for communicating between on-cloud and off-cloud nodes
- not yet released

## Semantics, semantics, semantics!

# Process layer semantics

We started implementing the process layer...

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What is the behaviour supposed to be?

What is the spec exactly?

- original paper says the message passing is "**asynchronous, reliable, and buffered**" but little more

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We started implementing the process layer...

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What is the spec exactly?

- original paper says the message passing is "**asynchronous, reliable, and buffered**" but little more

For example, what does this do?

```
do link p; send p "hi!"; unlink p
```

- does the link happen before the send?
- does the unlink guarantee the message was delivered?
- are the link operations sync or async?
- any reliability guarantee on message delivery?

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# Process layer semantics

Remember? "If in doubt, do it the way Erlang does it."

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What is the Erlang spec exactly?

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**The important questions**

- behaviour of message passing between two processes?
- behaviour of linking and monitoring?

# Message passing guarantees

Meaning of “reliable ordered” message delivery

Process A sends messages to process B:

$m_1$, $m_2$, $m_3$, ...

Process B may receive any **prefix**.

For example receiving $m_1$, $m_3$ cannot happen

The Erlang FAQ says

> *“if you think TCP guarantees delivery, which most people probably do, then so does Erlang”*

# Message passing guarantees

## Meaning of “reliable ordered” message delivery

Process A sends messages to process B:

$m_1, m_2, m_3, \ldots$

Process B may receive any **prefix**.

For example receiving $m_1, m_3$ cannot happen

The Erlang FAQ says

> *“if you think TCP guarantees delivery, which most people probably do, then so does Erlang”*

But it turns out Erlang does **not** guarantee this.

Process B **can** receive just $m_1, m_3$

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# Erlang semantics

Erlang formal semantics guarantees ordered messaging between pairs of processes.

It does not guarantee reliable delivery: intermediate messages can be dropped.

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Erlang formal semantics guarantees ordered messaging between pairs of processes.

It does not guarantee reliable delivery: intermediate messages can be dropped.

In practice dropping messages is rare but can happen when Erlang nodes are **disconnected** and **reconnected**.

# Proposed future Erlang semantics

We found a good paper:

- Svensson et al. *A unified semantics for future Erlang*, Erlang workshop 2010

They propose what they think Erlang semantics **should** be

- formal specification
- **does** guarantee reliable ordered message delivery
- simplified linking and monitoring
- everything is asynchronous
- covers node disconnect and reconnect (mostly)

We took this as the spec for our implementation.

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We took this as the spec for our implementation.

*If in doubt, do it the way ~~Erlang does it~~*
*the Erlang people now think Erlang* ***ought*** *to do it*

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# Revisiting the example

So what does does this do now?

```
do link p; send p "hi!"; unlink p
```

- all asynchronous
- link is **not** ordered wrt. send
- so this code guarantees almost nothing

# Revisiting the example

So what does does this do now?

```
do link p; send p "hi!"; unlink p
```

- all asynchronous
- link is **not** ordered wrt. send
- so this code guarantees almost nothing

What we probably want instead is

```
do link p; send p "hi!"; reply ← expect; unlink p
```

- order of link vs send does not matter here

Lessons

- linking has very little to do with message delivery
- to assure delivery you must receive a reply

# Reliable delivery

## Question

Why does Erlang not provide reliable delivery when TCP does?

TCP is connection oriented

- you establish a connection to an address and send data over the connection
- network failure is reflected as the connection closing

Erlang (and Cloud Haskell) are connectionless

- you send messages direct to addresses (ProcessIds)

If we allow node reconnects it is hard to mix reliable delivery and connectionless style

# Node disconnect and reconnect

**Example**

Process A sends messages to process B: $m_1$, $m_2$, $m_3$, ...

Now the network between A and B fails. What should we do?

The nodes may be disconnected temporarily or permanently

# Node disconnect and reconnect

**Example**

Process A sends messages to process B: $m_1$, $m_2$, $m_3$, ...

Now the network between A and B fails. What should we do?

The nodes may be disconnected temporarily or permanently

A few options

- buffer messages
- drop messages temporarily
- drop messages permanently (do not allow reconnect)

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# Node disconnect and reconnect

Current Erlang behaviour

- buffers messages temporarily
- then drops messages
- sacrifices reliability property

"Unified semantics for future Erlang"

- drops messages to dead nodes
- buffers messages to disconnected nodes
- keeps reliability property
- impossible to implement

# Node disconnect and reconnect

Our proposal for Cloud Haskell

- drop messages permanently (by default)
- this keeps the reliability property (!!)
- explicit reconnect primitive
- reconnect to accept intermediate message loss

We think this is a reasonable compromise

- simple reliability guarantee
- most code does not need to handle reconnect
  - it simply fails on the initial disconnect
- code that wants to handle reconnect explicitly opts in and accepts the reality of message loss

# Implementation status

# Current state of the implementation

Current status

- Covers the full API
- Made a first release and several minor bug-fix releases
- Reasonable test suite
- Reasonable performance

Ready for serious experiments, but not yet for serious use.

# Current state of the implementation

Significant TODOs

- Larger scale testing
- Node disconnect and reconnect needs more work and testing
- More demos
- Comparative benchmarking needed

Wishlist

- Shared memory transport
- SSH transport
- Ability to use multiple transports
- Implementation of the ‘static’ language extension
- Higher level libraries, e.g. Erlang OTP’s `gen_server`

Contributions welcome

# Early benchmarks

Transport layer microbenchmark of the TCP implementation

- minimal overhead compared to `network` package
- some latency overhead compared to C
  - primarily issues in the threaded RTS and GHC I/O manager

Process layer microbenchmark comparison with the prototype

- approx 4x lower latency
- approx 200x greater throughput

(running on Azure infrastructure)

This is **not** a surprising result:
the prototype uses **synchronous** message send

Benchmarking against Erlang is required

# Cloud Haskell Packages

Cloud Haskell Packages on Hackage

| | |
|---|---|
| `distributed-process` | Main API, Process etc |
| `distributed-process-simplelocalnet` | Simple backend |
| `distributed-process-azure` | Windows Azure backend |
| `network-transport` | Transport interface |
| `network-transport-tcp` | TCP implementation |

Sources and documentation on github

`http://github.com/haskell-distributed/distributed-process`

Thanks!

Questions?

# Extra slides

# Initialisation

Initialisation sequence looks something like

```
import Control.Distributed.Process
import Network.Transport.TCP

init :: (...) → Process () → IO ()
init config initialProcess = do
  transport  ← createTransport config
  localnode ← newLocalNode transport
  runProcess localnode initialProcess
```

- initialise a transport, with some transport-specific config
- initialise the local Cloud Haskell node
- run the initial process

This is all hidden in a Cloud Haskell backend

# Ping pong example

```haskell
newtype Ping = Ping ProcessId deriving (Binary, Typeable)

ping :: Process ()
ping = do self ← getSelfPid
          Ping partner ← expect
          send partner (Ping self)
          say "ping!"
          ping

initialProcess _ = do nid   ← getSelfNode
                      ping1 ← spawn nid ping__closure
                      ping2 ← spawn nid ping__closure
                      send ping1 (Ping ping2)

$(remotable ['ping])   -- Template Haskell magic

main = remoteInit (Just "config") [__remoteCallMetaData]
           initialProcess
```

# Asyncronous primitives

```
spawn :: NodeId → Closure (Process ()) → Process ProcessId
spawn nid proc = do
  us     ← getSelfPid;
  mRef ← monitorNode nid
  sRef  ← spawnAsync nid (childClosure proc)
  mPid ← receiveWait
    [matchIf
        (λ(DidSpawn ref _) → ref ≡ sRef)
        (λ(DidSpawn _ pid) → return (Right pid))
    , matchIf
        (λ(NodeMonitorNotification ref _ _) → ref ≡ mRef)
        (λ(NodeMonitorNotification _ _ err) → return (Left err))
    ]
  unmonitor mRef
  case mPid of
    Left _err  → return (nullProcessId nid)
    Right pid → send pid () ≫ return pid
```

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