

# Network servers

## Haskell and Cryptocurrencies

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2020-08-07



# Goals

- Revisit servers.
- `MVar`s,
- Servers with state.
- More about `Async` and `STM`.

This lecture follows parts of Chapters 10 and 12 of Simon Marlow's book "Parallel and Concurrent Programming in Haskell" rather closely.

All errors are of course our own.

## Shouting server, again

```
main :: IO ()
main = do
  s <- listenOn (PortNumber 8765)
  forever $ do
    (h, _, _) <- accept s
    forkIO $ handleClient h
handleClient :: Handle -> IO ()
handleClient h = do
  hSetBuffering h LineBuffering
  forever $ do
    line <- hGetLine h
    hPutStrLn h (map toUpper line)
```

# Observation

- Every client process is completely independent of each other.
- Therefore, no state is needed in the server.

## Adding state

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# A server that counts the clients

## Goal

Server accepts connections and reports on request the number of currently connected clients.

We need to maintain the current number of clients as state.

## Options for maintaining state

- A `TVar` with atomic access.



# Options for maintaining state

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- A `TVar` with atomic access.
- An `MVar` with synchronized access.
- An `IORef`, as long as we update it atomically.

- An `MVar a` is mutable location that is either empty or contains a value of type `a`.
- It has two fundamental operations:
  - `putMVar :: MVar a -> a -> IO ()` which fills an `MVar` if it is empty and blocks otherwise, and
  - `takeMVar :: MVar a -> IO a` which empties an `MVar` if it is full and blocks otherwise.

They can be used in multiple different ways:

- as synchronized mutable variables,
- as channels, with `takeMVar` and `putMVar` as receive and send, and
- as a binary semaphore `MVar ()`, with `takeMVar` and `putMVar` as wait and signal.

## Applicability of `MVar`s

- `MVar`s offer more flexibility than `IORef`s, but less flexibility than `TVar`s.
- They are appropriate for building synchronization primitives and performing simple interthread communication;
- however they are very simple and susceptible to race conditions, deadlocks or uncaught exceptions.
- Do not use them if you need to perform larger atomic operations such as reading from multiple variables: Use `TVar`s instead.

## MVar fairness guarantee

- No thread can be blocked indefinitely on an MVar unless another thread holds that MVar indefinitely.
- One usual implementation of this fairness guarantee is that threads blocked on an MVar are served in a first-in-first-out fashion, but this is not guaranteed in the semantics.
- TVar s do *not* give the same guarantee.

## MVar API (excerpt)

```
newEmptyMVar :: IO (MVar a)
newMVar      :: a -> IO (MVar a)
```

```
putMVar :: MVar a -> a -> IO ()
takeMVar :: MVar a -> IO a
readMVar :: MVar a -> IO a
```

```
tryPutMVar :: MVar a -> a -> IO Bool
tryTakeMVar :: MVar a -> IO (Maybe a)
tryReadMVar :: MVar a -> IO (Maybe a)
```

```
modifyMVar :: MVar a -> (a -> IO (a, b)) -> IO b
withMVar   :: MVar a -> (a -> IO b) -> IO b
```

## Creating and maintaining a TVar

```
main :: IO ()
main = do
  s <- listenOn (PortNumber 8765)
  conns <- newTVarIO 0 -- new
  forever $ do
    (h, _, _) <- accept s
    forkFinally -- changed
      (handleClient h conns)
      (const $ removeClient h conns)
```



## forkFinally

From `Control.Concurrent`:

```
forkFinally ::  
  IO a -> (Either SomeException a -> IO ())  
  -> IO ThreadId
```

Executes the second argument once the thread is about to finish, whether normally or via an exception.

## Cleaning up a client

```
removeClient :: Handle -> TVar Int -> IO ()
removeClient h conns = do
  atomically $ modifyTVar' conns (\ x -> x - 1)
  hClose h
```

We can also use this to explicitly close the handle, which is better than relying on garbage collection.

## Handling a client

```
handleClient :: Handle -> TVar Int -> IO ()
handleClient h conns = do
  atomically $ modifyTVar' conns (\x -> x + 1)
  hSetBuffering h LineBuffering
  forever $ do
    line <- hGetLine h
    count <- readTVarIO conns
    hPrint h count
```

# Reporting changes asynchronously

## Goal

Rather than reporting the number of connected clients on request, the server should asynchronously report the number of clients whenever it changes.

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One option is to maintain the list of handles rather than the number of clients.

## Maintaining a list of handles

```
main :: IO ()
main = do
  s <- listenOn (PortNumber 8765)
  conns <- newTVarIO [] -- changed type
  forkIO (monitor 0 conns) -- new
  forever $ do
    (h, _, _) <- accept s
    forkFinally
      (handleClient h conns)
      (const $ removeClient h conns)
```

## Registering and removing a client

```
removeClient :: Handle -> TVar [Handle] -> IO ()
removeClient h conns = do
    atomically $ modifyTVar' conns (delete h)
    hClose h
```

```
handleClient :: Handle -> TVar [Handle] -> IO ()
handleClient h conns = do
    hSetBuffering h LineBuffering
    atomically $ modifyTVar conns (h :)
    forever $ hGetLine h -- hack
```

## Monitoring changes

```
monitor :: Int -> TVar [Handle] -> IO ()
monitor count conns = do
  (handles, newcount) <- atomically $ do
    handles <- readTVar conns
    let newcount = length handles
    when (count == newcount) retry
    return (handles, newcount)
  mapM_ (\h -> hPrint h newcount) handles
  monitor newcount conns
```



# Distributing handles is problematic

- We potentially have to deal with disappearing handles / exceptions in several places.
- If multiple parts of the program access the same handle, outputs and inputs could become interleaved in unexpected ways.

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- If multiple parts of the program access the same handle, outputs and inputs could become interleaved in unexpected ways.

A better solution:

- Let every client handler deal with communication alone.
- Use a (broadcast) channel for the messages.

# Channels

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# Channels (STM)

A thread-safe FIFO queue.

```
data TChan a  -- abstract
newTChan      :: STM (TChan a)
newBroadcastTChan :: STM (TChan a)  -- write-only
dupTChan      :: TChan a -> STM (TChan a)
readTChan     :: TChan a -> STM a
writeTChan    :: TChan a -> a -> STM ()
```

## On channels

- Items written into a channel do not get lost.
- Items will be read in the order they have been written (first-in first-out, FIFO).
- Items can be read only once (even if accessed concurrently).

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Using `dupTChan`:

- We create a new empty channel.
- Items written to the new or original channel will be available on both.
- So in this case, any item written can be read twice.

## The main program

```
main :: IO ()
main = do
  s <- listenOn (PortNumber 8765)
  conns <- newTVarIO 0 -- back to integers
  bchan <- newBroadcastTChanIO -- new
  forkIO (monitor 0 conns bchan)
  forever $ do
    (h, _, _) <- accept s
    forkFinally
      (handleClient h conns bchan) -- changed
      (const $ removeClient h conns)
```

## Handling new clients

```
handleClient ::  
  Handle -> TVar Int -> TChan String -> IO ()  
handleClient h conns bchan = do  
  chan <- atomically $ dupTChan bchan  
  atomically $ modifyTVar' conns (\ x -> x + 1)  
  hSetBuffering h LineBuffering  
  void $ input `race` output chan  
where  
  input      = forever $ hGetLine h  
  output chan = forever $ do  
    line <- atomically $ readTChan chan  
    hPutStrLn h line
```



## Another Async function

```
race :: IO a -> IO b -> IO (Either a b)
```

- Runs two operations concurrently.
- Returns the one that finishes first.
- Cancels the other.
- Propagates possible exceptions.

## Removing a client (as earlier)

```
removeClient :: Handle -> TVar Int -> IO ()  
removeClient h conns = do  
  atomically $ modifyTVar' conns (\ x -> x - 1)  
  hClose h
```

# Monitoring

```
monitor :: Int -> TVar Int -> TChan String -> IO ()
monitor count conns bchan = do
  newcount <- atomically $ do
    newcount <- readTVar conns
    when (count == newcount) retry
  return newcount
atomically $ writeTChan bchan (show newcount)
monitor newcount conns bchan
```

# Implementing channels

---

## Looking into TChan s

It turns out that TChan s are built on top of other STM primitives.

```
data TChan a =  
  TChan  
    (TVar (TVarList a))  -- channel head  
    (TVar (TVarList a))  -- channel end
```

```
type TVarList a = TVar (TList a)  
data TList a = TNil | TCons a (TVarList a)
```

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```
type TVarList a = TVar (TList a)  
data TList a = TNil | TCons a (TVarList a)
```

- Two pointers.
- TNil means no element there.
- Channel end always points at TNil.

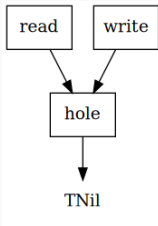
## Creating a new channel

```
newTChan :: STM (TChan a)
newTChan = do
  hole  <- newTVar TNil
  read  <- newTVar hole
  write <- newTVar hole
  return (TChan read write)
```

## Creating a new channel

```
newTChan :: STM (TChan a)
newTChan = do
  hole  <- newTVar TNil
  read  <- newTVar hole
  write <- newTVar hole
  return (TChan read write)
```

- In a new channel, head and end point to the same `TVar`.





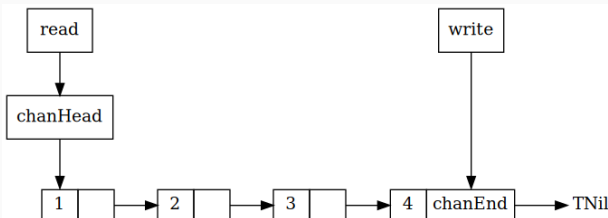
## Reading from a channel

```
readTChan :: TChan a -> STM a
readTChan (TChan read _write) = do
  chanHead <- readTVar read
  items    <- readTVar chanHead
  case items of
    TNil          -> retry
    TCons a rest  -> do
      writeTVar read rest
      return a
```

- Only the head (read) pointer is used.
- If nothing there, `TNil`, we `retry`.
- Otherwise, we move the pointer to the right.

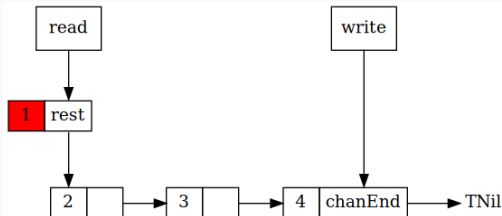
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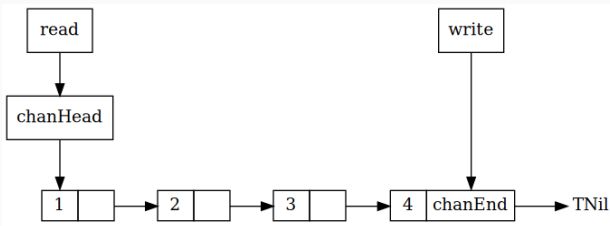
## Writing to a channel

```
writeTChan :: TChan a -> a -> STM ()
writeTChan (TChan _read write) a = do
  chanEnd    <- readTVar write
  newChanEnd <- newTVar TNil
  writeTVar chanEnd (TCons a newChanEnd)
  writeTVar write newChanEnd
```

- Only the tail (write) pointer is used.
- Write pointer always points at `TNil`.
- We write the new item and move the pointer to the right.

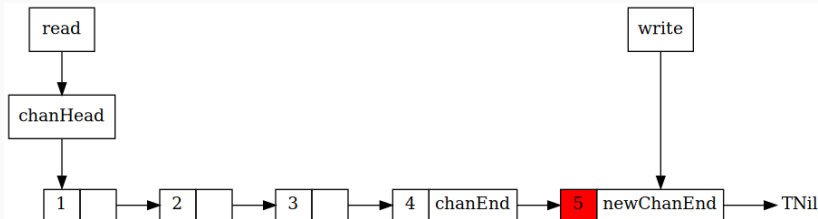
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writeTChan (TChan _read write) a = do  
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  newChanEnd <- newTVar TNil  
  writeTVar chanEnd (TCons a newChanEnd)  
  writeTVar write newChanEnd
```



## Writing to a channel

```
writeTChan :: TChan a -> a -> STM ()  
writeTChan (TChan _read write) a = do  
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  writeTVar chanEnd (TCons a newChanEnd)  
  writeTVar write newChanEnd
```



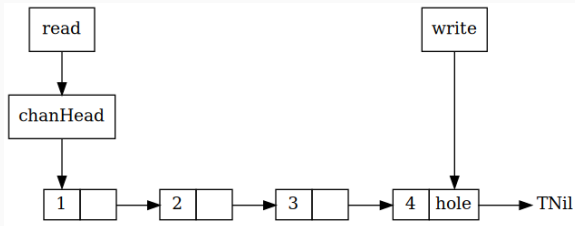
## Duplicating a channel

```
dupTChan :: TChan a -> STM (TChan a)
dupTChan (TChan _read write) = do
  hole <- readTVar write
  newChanHead <- newTVar hole
  return (TChan newChanHead write)
```

- A duped channel starts out empty.
- We duplicate the hole at the write end of the channel ...
- ... and turn that into a new read pointer.

## Duplicating a channel

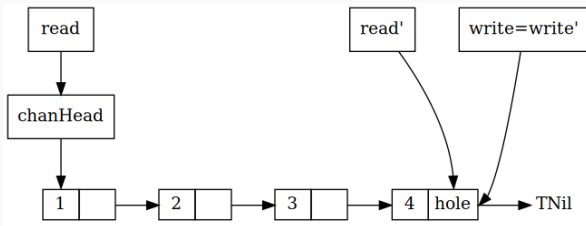
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## Duplicating a channel

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```



## Broadcasting channels

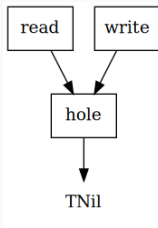
```
newTChan :: STM (TChan a)
newTChan = do
  hole  <- newTVar TNil
  read  <- newTVar hole
  write <- newTVar hole
  return (TChan read write)
```

This is the old version:

- If a channel is written to but never read from, the items cannot be garbage collected and stay in memory.

# Broadcasting channels

```
newTChan :: STM (TChan a)
newTChan = do
  hole  <- newTVar TNil
  read  <- newTVar hole
  write <- newTVar hole
  return (TChan read write)
```



## Broadcasting channels

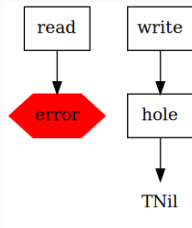
```
newBroadcastTChan :: STM (TChan a)
newBroadcastTChan = do
  hole  <- newTVar TNil
  read  <- newTVar (error "must use dupTChan")
  write <- newTVar hole
  return (TChan read write)
```

This is the new version:

- This is a write-only channel.
- Readable channels can still be created via `dupTChan`.

## Broadcasting channels

```
newBroadcastTChan :: STM (TChan a)
newBroadcastTChan = do
  hole <- newTVar TNil
  read  <- newTVar (error "must use dupTChan")
  write <- newTVar hole
  return (TChan read write)
```



# A chat server

---

## Informal specification

- When client connects, server requests nickname.  
Nickname must be fresh, otherwise server will ask again.
- Each line from the client is one of the following:  
`/tell <name> <message>`  
`/kick <name>`  
`/quit`  
`<message>`
- Broadcast notifications on (dis)connects.

