Introduction to STM

Part II: Transactional LEGOs

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Preface

Recap (1/2)

STM = Optimistic concurrency control

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A `TVar` is a transactional variable

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Recap (1/2)

STM = Optimistic concurrency control

A `TVar` is a transactional variable

Operations on `TVar`s are called STM transactions

Run transactions with `atomically`; combine with `orElse`

Recap (2/2)

Transactions get rerun on conflicts. We know because of a log

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You can also call `retry` to rerun yourself

The runtime reruns the transaction after its inputs change

Use this for blocking operations

Today (by request)

Using `TVar` as a piece of LEGO

Let's create some of the datatypes in `stm`

If we have time, we can look at `stm-containers`

Note: this is all other people's code

Transactional LEGOs

`TVars` are nice

But sometimes, we want something more

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Certain situations call for more datatypes

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But sometimes, we want something more

Certain situations call for more datatypes

The `stm` package provides a bunch of them

Stuff in `stm`

`TVar` Variables

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`TArray` Arrays (not discussing these)

Stuff in `stm`

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`TArray` Arrays (not discussing these)

`TMVar` Variable which is either empty or full

Stuff in `stm`

`TVar`	Variables
`TArray`	Arrays (not discussing these)
`TMVar`	Variable which is either empty or full
`TQueue`	Queues (bounded: `TBQueue`)
`TChan`	Channels (slower than queues, but support broadcast)

TMVar

Introducing `TMVar a`

Empty or filled (name comes from `MVar`, more later)

Can be used as a synchronization primitive

```
newTMVar :: a -> STM (TMVar a)
newEmptyTMVar :: STM (TMVar a)

putTMVar  :: TMVar a -> a -> STM () -- blocks
takeTMVar :: TMVar a -> a -> STM a  -- blocks
```

Can we build `TMVar` ourselves?

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Really. Add a `newtype` and that's the `stm` implementation

```haskell
newtype TMVar a = TMVar (TVar (Maybe a))

newTMVar :: a -> STM (TMVar a)
newTMVar contents = do
  inner <- newTVar (Just contents)
  pure (TMVar inner)
```

```haskell
newtype TMVar a = TMVar (TVar (Maybe a))

newEmptyTMVar :: STM (TMVar a)
newEmptyTMVar = do
  inner <- newTVar Nothing
  pure (TMVar inner)
```

```haskell
putTMVar :: TMVar a -> a -> STM ()
putTMVar (TMVar inner) newContents = do
  contents <- readTVar inner
  case contents of
    Nothing -> do
      writeTVar inner (Just newContents)
      pure ()
    Just _ -> retry
```

```haskell
takeTMVar :: TMVar a -> STM a
takeTMVar (TMVar inner) = do
  contents <- readTVar inner
  case contents of
    Nothing -> retry
    Just c -> do
      writeTVar inner Nothing
      pure c
```

`MVar`

`TMVar`

`MVar`

Defined in `Control.Concurrent.MVar`

`TMVar`

Defined in `Control.Concurrent.STM.TMVar`

`MVar`

Concurrent Haskell (1996)

`TMVar`

Composable Memory Transactions (2006)

`MVar`

(First come, first serve) fairness

`TMVar`

`No` fairness guarantees

`MVar`

Lower level tool. Can be used against starvation

`TMVar`

High level convenient STM interface

TQueue

Introducing `TQueue a`

Unbounded, first-in first-out, queue

$O(1)$ inserts and reads (amortized).

```haskell
newTQueue :: STM (TQueue a)

writeTQueue :: TQueue a -> a -> STM ()
readTQueue :: TQueue a -> STM a -- blocks
```

Can we build `TQueue a` ourselves?

Again, yes. In this case using two `TVar [a]`s

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Again, yes. In this case using two `TVar [a]`s

```
data TQueue a
  = TQueue (TVar [a]) -- waiting to be read
           (TVar [a]) -- written
```

```haskell
data TQueue a = TQueue (TVar [a]) (TVar [a])

newTQueue :: STM (TQueue a)
newTQueue = do
  read  <- newTVar []
  write <- newTVar []
  pure (TQueue read write)
```

```haskell
data TQueue a = TQueue (TVar [a]) (TVar [a])

writeTQueue :: TQueue a -> a -> STM ()
writeTQueue (TQueue _read write) a = do
  listend <- readTVar write
  writeTVar write (a:listend)
```

```haskell
data TQueue a = TQueue (TVar [a]) (TVar [a])

readTQueue :: TQueue a -> STM a
readTQueue (TQueue read write) = do
  xs <- readTVar read
  case xs of
    (x:xs') -> do
      writeTVar read xs'
      pure x
    [] -> do
      --
      -- What should go here??
      --
```

```haskell
data TQueue a = TQueue (TVar [a]) (TVar [a])

readTQueue :: TQueue a -> STM a
readTQueue (TQueue read write) = do
  xs <- readTVar read
  case xs of
    (x:xs') -> do
      writeTVar read xs'
      pure x
    [] -> do
      -- Get the contents of `write`, reverse, and
      -- store in `read`. (retry if `write` is empty).
      -- This is where the "amortized" came from.
```

Why add bounds?

Bounded queue: configurable (fixed) capacity. Writes block (`retry` with STM) if the new size is larger than the capacity.

Useful for implementing backpressure in our systems.

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We need to know the sizes of the `read` and `write` lists.

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For every insert, we can see if we exceed capacity.

```
data TBQueue a
  = TBQueue (TVar Int) -- read capacity
            (TVar [a]) -- waiting to be read
            (TVar Int) -- write capacity
            (TVar [a]) -- written
```

```haskell
newTBQueue :: Int -> STM (TBQueue a)
newTBQueue size = do
  read  <- newTVar []
  write <- newTVar []
  rsize <- newTVar 0
  wsize <- newTVar size
  pure (TBQueue rsize read wsize write)
```

```haskell
writeTBQueue :: TBQueue a -> a -> STM ()
writeTBQueue (TBQueue rsize _read wsize write) a = do
  w <- readTVar wsize
  if (w /= 0)
    then do writeTVar wsize $! w - 1
    else do
          --
          --
          -- What should go here?
          --
          --
  listend <- readTVar write
  writeTVar write (a:listend)
```

```haskell
writeTBQueue :: TBQueue a -> a -> STM ()
writeTBQueue (TBQueue rsize _read wsize write) a = do
  w <- readTVar wsize
  if (w /= 0)
    then do writeTVar wsize $! w - 1
    else do
          -- Figure out if we have read capacity.
          -- Retry if not.
          --
          -- If we have some, swap the read and
          -- write capacities and subtract 1.
  listend <- readTVar write
  writeTVar write (a:listend)
```

```haskell
writeTBQueue :: TBQueue a -> a -> STM ()
writeTBQueue (TBQueue rsize _read wsize write) a = do
  w <- readTVar wsize
  if (w /= 0)
    then do writeTVar wsize $! w - 1
    else do
          r <- readTVar rsize
          if (r /= 0)
            then do writeTVar rsize 0
                    writeTVar wsize $! r - 1
            else retry
  listend <- readTVar write
  writeTVar write (a:listend)
```

stm-containers

Sometimes you want an STM (hash)map

This can be useful whenever a Hashmap is useful

Example: user-ID to rate limiting information.

A first idea might be `TVar (HashMap (TVar a))`, but that's not ideal.

Why not `TVar (HashMap (TVar a))`?

Updates to invidivual keys are fine.

Updates to the entire `HashMap` change the outer `TVar`

This imposes a bottleneck for some workloads (contention on key addition/removal)

We want to decrease contention

This requires splitting the workload into some chunks.

It does basically mean “implement `Map` again”.

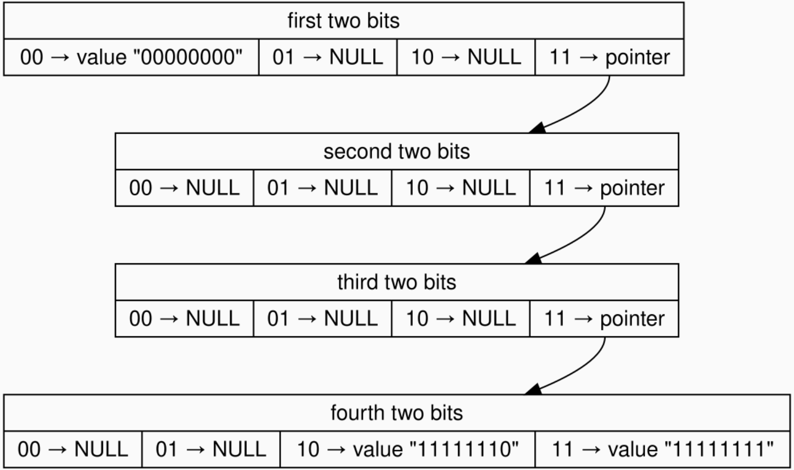
Method: a “Hash Array Mapped Trie”

HAMT, briefly

Each key/value-pair is stored by:

1. Hashing the key (yielding a binary value)
2. Storing the value in the Trie at the location determined by the hash

More at: https://idea.popcount.org/2012-07-25-introduction-to-hamt/



Picture credit: https://idea.popcount.org/2012-07-25-introduction-to-hamt/

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We sometimes need to insert new levels, but this is waaay better than global contention.

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We sometimes need to insert new levels, but this is waaay better than global contention.

A real implementation is more involved and has compression and an bunch of other things.

More at: https://nikita-volkov.github.io/stm-containers/

Summary

Summary

`TMVar a = TVar (Maybe a)`

`TQueue a = TQueue (TVar [a]) (TVar [a])`

Want bounds? Add counts for read and write capacity!

`stm-containers` works with a Hash Array Mapped Trie to avoid contention on structural updates

Tomorrow

First hour: excersises

Then: implementation notes and semantics