Practical Verification of Concurrent Haskell Programs

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Aim: verification of Haskell concurrency models through Agda2hs.

Haskell: a mainstream strongly typed functional language

Agda: a non-mainstream strongly typed, total functional language with dependent types

Agda2hs: automatically translates Agda code to readable Haskell – combine the best of both worlds!

Concurrent Haskell: MVars are used as mutually exclusive, mutable shared variables. They are 'boxes' that may contain a value, that can be read from when full, and written to when empty.

1. MOTIVATION

- Formal verification. As a dependently typed language, Agda allows for formal proofs about program correctness. This significantly improves confidence in the program.
- **Concurrency**. Notoriously difficult to test; instead we can define essential properties that ensure the correctness of our program. These require formal proofs.

2. METHOD

- 1. Port Haskell concurrency model to Agda. Check it translates to correct Haskell with Agda2hs.
- 2. Prove correctness of programs with the help of Agda's dependent type system - with a focus on the occurrence of deadlocks.

3. CONCURRENCY MODEL

- Haskell concurrency libraries: low-level implementation, difficult to port directly.
- Claessen 1999 [1]: concurrency monad transformer that adds a simple form of concurrency to any monad:

type C $m \alpha = (\alpha \rightarrow \text{Action } m) \rightarrow \text{Action } m$

data Action m

- = Atom (*m* (Action *m*))
- Fork (Action m) (Action m)
- Stop

Concurrency monad transformer and accompanying Action datatype

round :: Mon	ad	$m \Rightarrow [Action]$
round []	=	return ()
round $(a:as)$	=	case a of
Atom a_m	\rightarrow	do $a' \leftarrow a_m$
Fork $a_1 a_2$	\rightarrow	round (as +
Stop	\rightarrow	round as

Round robin scheduling function for interleaving actions

- Can be used to simulate Haskell MVars
- Combine with pure IO model with memory representation [3], so Agda can evaluate the programs

4. FROM HASKELL TO AGDA (AND BACK) (1)

```
Circumvent Haskell's newtype declarations:
record C (m : Set → Set) (a : Set) : Set where
    constructor Conc
    field
        act : (a \rightarrow Action m) \rightarrow Action m
open C public
{-# COMPILE AGDA2HS C #-} Agda2hs
data C m a = Conc{act :: (a -> Action m) ->
Action m}
```

 $m] \rightarrow m$ ()

; round (as ++ [a']) $++ [a_1, a_2])$

4. FROM HASKELL TO AGDA (AND BACK) (2)

```
To meet Agda's termination requirement, add 'fuel' to
enforce termination of non-terminating functions:
round : { Monad m } \rightarrow List (Action m) \rightarrow
     MyNat \rightarrow m Bool
round [] = return True
round xs Zero = return False
round (Stop :: xs) (Suc n) = round xs n
round (Atom x :: xs) (Suc n) = ...
round (Fork x y :: xs) (Suc n) = ...
{-# COMPILE AGDA2HS round #-}
```

5. VERIFICATION

Interesting properties are mostly about specific concurrent programs, not about the models. We focus on:

• Absence of deadlocks. There is no program configuration in which all processes wait indefinitely for each other.

We can use the forced termination of our functions to prove whether our programs terminate or not, i.e. whether a deadlock occurs.

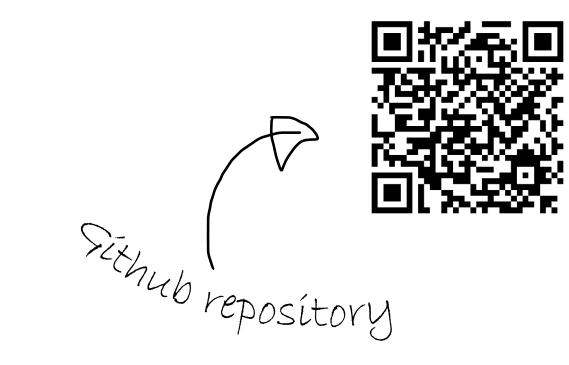
6. DEADLOCK PROOF

We can prove that this program does not terminate because it runs out of fuel:

```
mVarDeadlock : Bool
mVarDeadlock = runIOs (run (do
```

```
a <- newEmptyMVar
                b <- newEmptyMVar</pre>
                fork (do
                        takeMVar a fuel
                        writeMVar b 1 fuel)
                takeMVar b fuel
                writeMVar a 2 fuel
                ) (natToMyNat 100000))
{-# COMPILE AGDA2HS mVarDeadlock #-}
```

deadlock-proof : mVarDeadlock = False deadlock-proof = refl



7. RESULTS

- Ported Claessen's concurrency model to Agda with minor adjustments, generated readable Haskell with Agda2hs.
- Implemented a model for IO (Swierstra 2008) to enable reasoning about concurrent programs in Agda.
- Proven occurrence of deadlocks for simple concurrent programs with MVars.

8. LIMITATIONS

- Agda's requirements for totality and termination
- Deterministic round robin scheduler
- Assumed correspondence Haskell's IO with modeled 10

9. FUTURE WORK

- Devising alternatives for round robin scheduler
- Verifying more complex concurrent programs
- Verifying other properties
- Porting a simplified STM model to Agda [2]

10. REFERENCES

[1] K. Claessen, "A poor man's concurrency monad," Journal of Functional Programming, vol. 9, pp. 313–323, 1999.

[2] L. Hu, Compiling Concurrency Correctly Verifying Software Transactional Memory. PhD thesis, University of Nottingham, 6 2012.

[3] W. Swierstra, A functional specification of effects. PhD thesis, University of Nottingham, 11 2008.