

# Building a Parallel Haskell based on Arrows

*Martin Braun*

Großes Masterprojekt  
Universität Bayreuth  
Supervisor: Dr. Oleg Lobachev

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- 1 Functional Programming 101
  - Short intro
  - Arrows
- 2 Parallel Arrows
  - Introduction to Parallelism
  - Generalization to Arrows
  - ArrowParallel Implementations
- 3 Usability
  - Skeletons
  - Syntactic Sugar
- 4 Benchmarks
- 5 Further Notes

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# Functions

```

1 public static int fib(int x) {
2     if (x<=0)
3         return 0;
4     else if (x==1)
5         return 1;
6     else
7         return fib(x-2) + fib(x-1);
8 }

```

```

1 fib :: Int -> Int
2 fib x
3   | x <= 0 = 0
4   | x == 1 = 0
5   | otherwise =
6     ( fib (x - 2))
7     + (fib (x - 1))

```

- Functional programming equally powerful as imperative programming
- focused on the "what?" instead of the "how?"  
⇒ more concise ⇒ easier to reason about
- based on Lambda Calculus

# Arrow Definition (1)

Another way to think about computations:

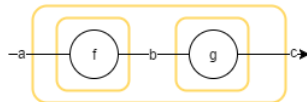
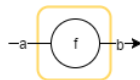


# Arrow Definition (2)

```
class Arrow arr where
  arr :: (a -> b) -> arr a b
```

```
(>>>) :: arr a b -> arr b c -> arr a c
```

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



# Functions $\in$ Arrows

Functions  $(- \rightarrow)$  are arrows:

```
1 instance Arrow (->) where
2   arr f = f
3   f >>> g = g . f
4   first f = \ (a, c) -> (f a, c)
```

# The Kleisli Type

## The Kleisli type

```
1 data Kleisli m a b = Kleisli { run :: a -> m b }
```

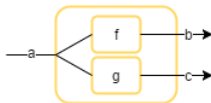
is also an arrow:

```
1 instance Monad m => Arrow (Kleisli m) where
2   arr f = Kleisli $ return . f
3   f >>> g = Kleisli $ \a -> f a >>= g
4   first f = Kleisli $ \(a,c) -> f a >>= \b -> return (b,c)
```

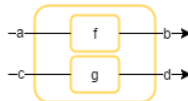


# Combinators

```
1 (&&&) :: arr a b -> arr a c -> arr a (b, c)
2 f &&& g = arr (\a -> (a, a)) >>> (f *** g)
```



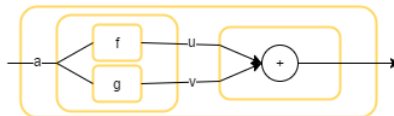
```
1 (***) :: arr a b -> arr c d -> arr (a, c) (b, d)
2 f *** g = first f >>> second g
```



# Arrow Example

Arrow usage example:

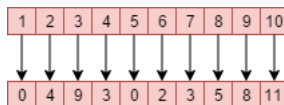
```
1 add :: Arrow arr => arr a Int -> arr a Int -> arr a Int
2 add f g = (f &&& g) >>> arr \(u, v) -> u + v
```



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In general, Parallelism can be looked at as:

1  $\text{parEvalN} :: [a \rightarrow b] \rightarrow [a] \rightarrow [b]$



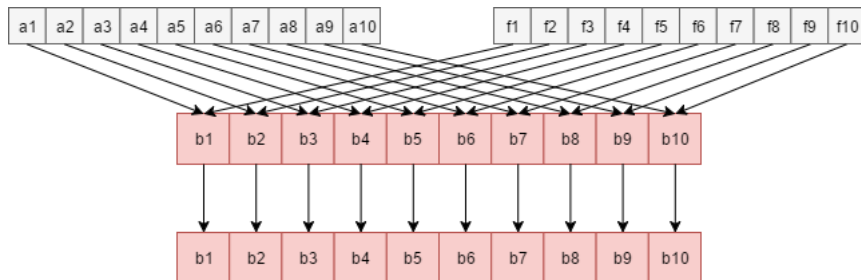
```
1 parEvalN :: [a -> b] -> [a] -> [b]
```

## Roadmap:

- Implement using existing Haskells
  - Multicore
  - ParMonad
  - Eden
- Generalize to Arrows
- Adapt Implementations
- Profit

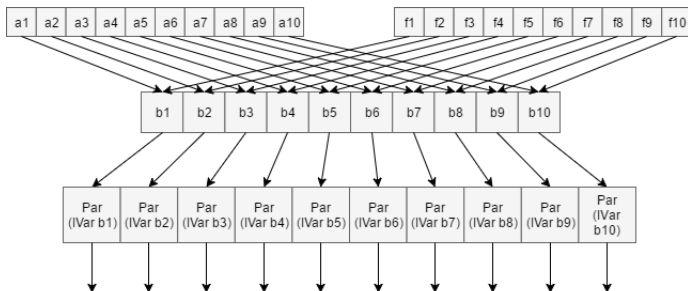
# Multicore Haskell

```
1 parEvalN :: (NFData b) => [a -> b] -> [a] -> [b]
2 parEvalN fs as = zipWith ($) fs as 'using' parList rdeepseq
```



# ParMonad

```
1 parEvalN :: (NFData b) => [a -> b] -> [a] -> [b]
2 parEvalN fs as = runPar $
3   (sequence $ map (spawnP) $ zipWith ($) fs as) >>= mapM get
```

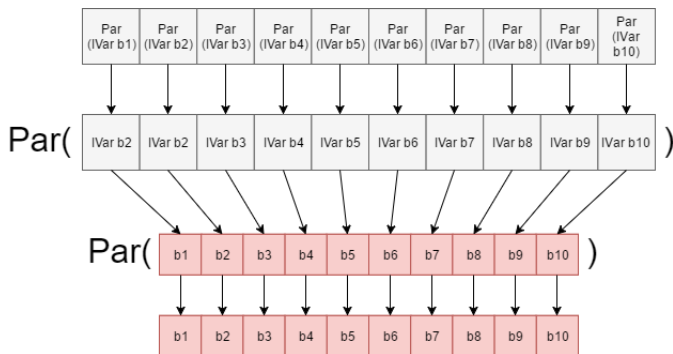


# ParMonad

```

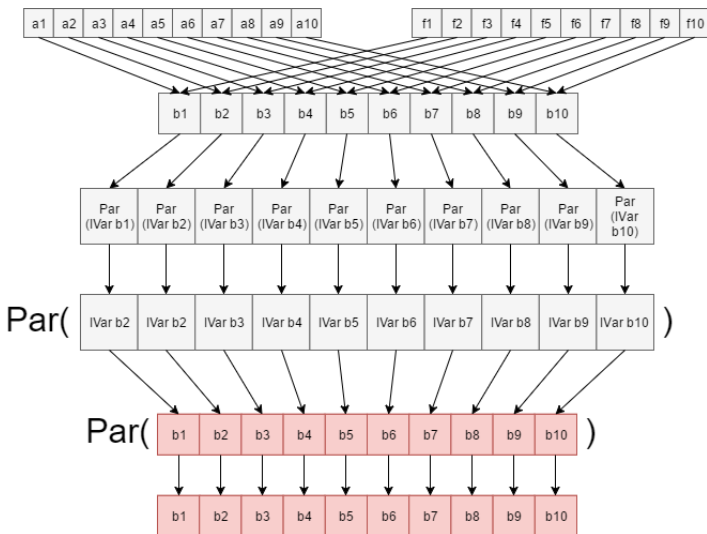
1 parEvalN :: (NFData b) => [a -> b] -> [a] -> [b]
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```



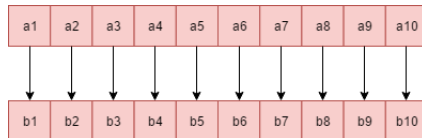


# ParMonad



# Eden

```
1 parEvalN :: (Trans a, Trans b) => [a -> b] -> [a] -> [b]
2 parEvalN fs as = spawnF fs as
```



# The ArrowParallel typeclass

Now, let's generalize:

```
1 parEvalN :: [a -> b] -> [a] -> [b]
```

# The ArrowParallel typeclass

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1 parEvalN :: [a -> b] -> [a] -> [b]
```

```
1 parEvalN :: (Arrow arr) => [arr a b] -> arr [a] [b]
```

# The ArrowParallel typeclass

Now, let's generalize:

```
1 parEvalN :: [a -> b] -> [a] -> [b]
```

```
1 parEvalN :: (Arrow arr) => [arr a b] -> arr [a] [b]
```

```
1 class Arrow arr => ArrowParallel arr a b where  
2   parEvalN :: [arr a b] -> arr [a] [b]
```

# The ArrowParallel typeclass

Now, let's generalize:

```
1 parEvalN :: [a -> b] -> [a] -> [b]
```

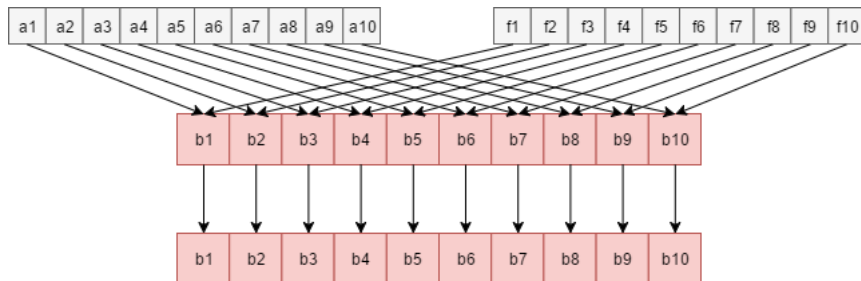
```
1 parEvalN :: (Arrow arr) => [arr a b] -> arr [a] [b]
```

```
1 class Arrow arr => ArrowParallel arr a b where  
2   parEvalN :: [arr a b] -> arr [a] [b]
```

```
1 class Arrow arr => ArrowParallel arr a b conf where  
2   parEvalN :: conf -> [arr a b] -> arr [a] [b]
```

# Multicore

```
1 instance (NFData b, ArrowApply arr, ArrowChoice arr) =>
2   ArrowParallel arr a b conf where
3     parEvalN _ fs = listApp fs >>>
4       arr (flip using $ parList rdeepseq)
```

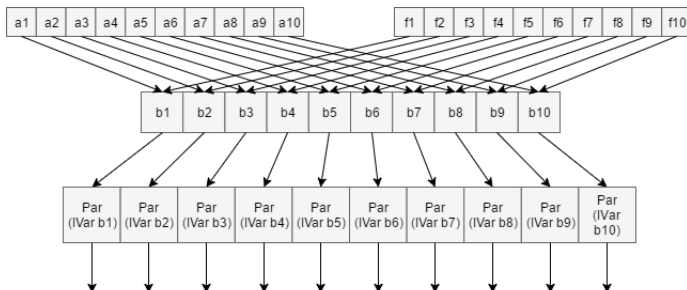


# ParMonad

```

1 instance (NFData b, ArrowApply arr, ArrowChoice arr) =>
2   ArrowParallel arr a b conf where
3     parEvalN _ fs =
4       (arr $ \as -> (fs, as)) >>>
5       zipWithArr (app >>> arr spawnP) >>>
6       ...

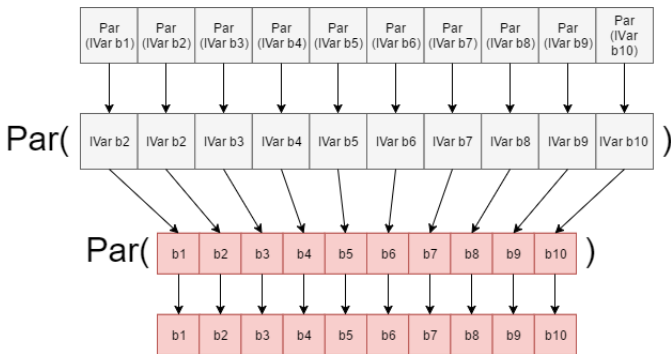
```





# ParMonad

```
1    ...  
2    arr sequence >>>  
3    arr (>>= mapM get) >>>  
4    arr runPar
```



# Eden (1)

For Eden we need separate implementations.

This is because of `spawnF`'s

```
1 spawnF :: (Trans a, Trans b) => [a -> b] -> [a] -> [b]
```

and `app`'s signature

```
1 app :: (ArrowApply arr) => arr (arr a b, a) b
```

which don't fit together.

# Eden (1)

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This is because of `spawnF`'s

```
1 spawnF :: (Trans a, Trans b) => [a -> b] -> [a] -> [b]
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and `app`'s signature

```
1 app :: (ArrowApply arr) => arr (arr a b, a) b
```

which don't fit together.

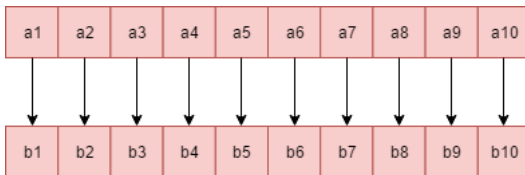
Hacky alternative:

```
1 class (Arrow arr) => ArrowUnwrap arr where  
2   arr a b -> (a -> b)
```

# Eden (2)

## Implementation for Functions

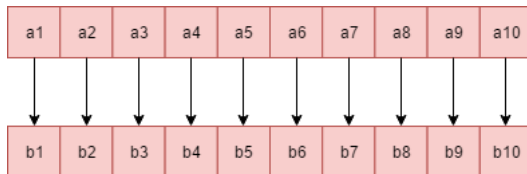
```
1 instance (Trans a, Trans b) => ArrowParallel (->) a b conf where
2   parEvalN _ fs as = spawnF fs as
```



# Eden (3)

Implementation for the Kleisli Type:

```
1 instance (Monad m, Trans a, Trans b, Trans (m b)) =>
2   ArrowParallel (Kleisli m) a b conf where
3   parEvalN conf fs =
4     (arr $ parEvalN conf (map (\(Kleisli f) -> f) fs)) >>>
5     (Kleisli $ sequence)
```



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# Skeletons... (1)

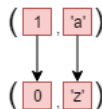
parEvalN, but **chunky**:

```
1 parEvalNLazy :: conf -> ChunkSize -> [arr a b] -> arr [a] [b]
```



parallel evaluation of **different typed functions**:

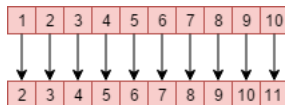
```
1 parEval2 :: conf -> arr a b -> arr c d -> arr (a, c) (b, d)
```



# Skeletons... (2)

map, but in **parallel**:

```
1 parMap :: conf -> arr a b -> arr [a] [b]
```



and others...

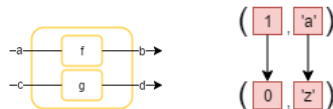


# Parallel Operators

```

1 (|***|) :: arr a b -> arr c d -> arr (a, c) (b, d)
2 (|***|) = parEval2 ()

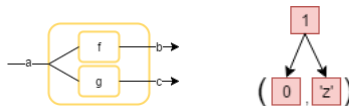
```



```

1 (|&&&|) :: arr a b -> arr a c -> arr a (b, c)
2 (|&&&|) f g = (arr $ \a -> (a, a)) >>> f |***| g

```



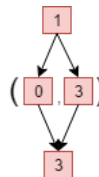
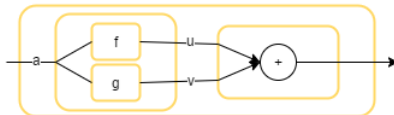
# Parallelism made easy

Parallel Evaluation made easy:

```

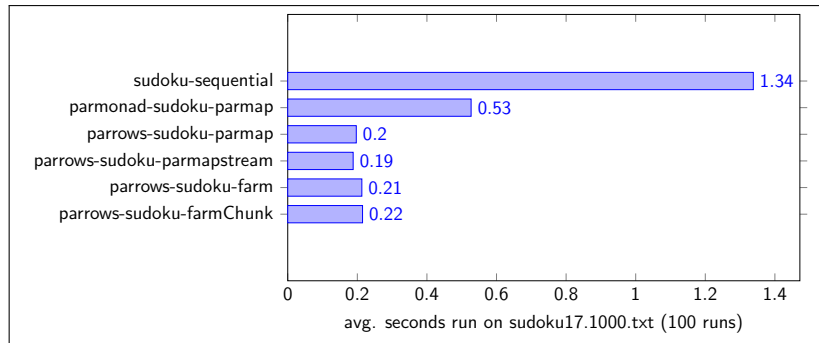
1 add :: Arrow arr => arr a Int -> arr a Int -> arr a Int
2 add f g = (f |&&&| g) >>> arr \(u, v) -> u + v

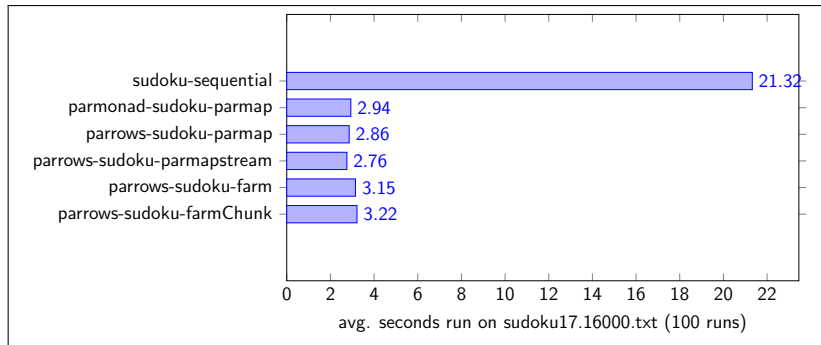
```

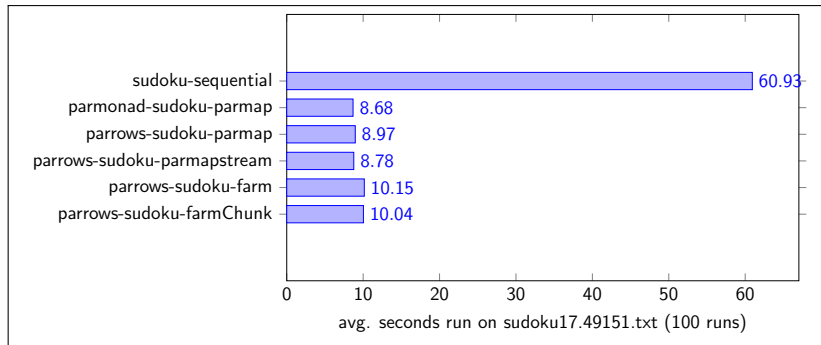


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- Run on: Core i7-3970X CPU @ 3.5GHz / 6C/12T
- compiled with ParMonad backend
- used Sudoku Benchmark from ParMonad examples







# Profit

So... What does this get us?

- Arrow based Haskell  $\Rightarrow$  **Free Parallelism** for (other) Arrows
- **Replaceable Backends**  $\Rightarrow$  Easier Development
- Arrows are quite **intuitive** for parallelism



## Further information

Paper draft:

<https://goo.gl/AJ9slI>

GitHub repository:

<https://github.com/s4ke/Parrows>

Frege Version in the works:

<https://goo.gl/oHbqh0>

