Shake:
Past, Present, Future

Neil Mitchell
shakebuild.com

Shake: a build system

- An alternative to Make, as a Haskell library
- About 9 years old
  - Built my PhD thesis
  - Proprietary SCB build system
  - Open-source reimplementation
  - Use in GHC
  - Research applications

PhD thesis builder

```
(<==) :: FilePath -> [FilePath] -> (FilePath -> FilePath -> IO ()) -> IO ()
(<==) to froms@(from:_) action = do
    b <- doesFileExist to
    rebuild <- if not b then return True else do
        from2 <- liftM maximum $ mapM getModificationTime froms
        to2 <- getModificationTime to
        return $ to2 < from2
    when rebuild $ do
        putStrLn $ "Building: " ++ to
        action from to
```

Shake: A Better Make

Neil Mitchell, Standard Chartered

Haskell Implementors Workshop 2010

OLD SLIDES: I'm no longer at Standard Chartered

An Example

```
import Development.Shake
main = shake $ do
  want ["Main.exe"]
  "Main.exe" *> \x -> do
      cs <- ls "*.c"
      let os = map (`replaceExtension` "obj") cs
      need os
      system $ ["gcc","-o",x] ++ os
  "*.obj" *> \x -> do
      let c = replaceExtension x "c"
      need [c]
      need =<< cIncludes c
      system ["gcc","-c",c,"-o",x]
```

Benefits of Shake

- A Haskell library for writing build systems
  - Can use modules/functions for abstraction/separation
  - Can use Haskell libraries (i.e. filepath)
- It's got the useful bits from Make
  - Automatic parallelism
  - Minimal rebuilds
- But it's better!
  - More accurate dependencies (i.e. the results of ls are tracked)
  - Can produce profiling reports (what took most time to build)
  - Can deal with generated files properly
  - Properly cross-platform

The Oracle

- The Oracle is used for non-file dependencies
  - What is the version of GHC? 6.12.3
  - What extra flags do we want? --Wall
  - `ls` is a sugar function for the Oracle

```
type Question = (String,String)
type Answer = [String]
oracle :: (Question -> Answer) -> Shake a -> Shake a
query :: Question -> Act Answer
```

The Implementation

NO DEPENDENCY GRAPH!

Parallelisation

- need/want both take lists of files, which run in parallel
- Try and build N rules in parallel
  - Done using a pool of N threads and a work queue
  - need/want put their jobs in the queue
- Add a `Building (MVar ())` in DataBase
- Shake uses a *random* queue
  - Jobs are serviced at random, *not* in any fair order
  - link = disk bound, compile = CPU bound
- Shake is highly parallel (in theory and practice)

Profiling

- Can record every system command run, and produce:

Average was 3.42 (interquartiles were 4.00 and 4.00)

Hot Tools

7.7s 7 × gcc

Hot Commands

1.8s gcc -c file3.c -o file3.obj

1.8s gcc -c file2.c -o file2.obj

Practical Use

- Relied on by an international team of people every day
- Building more than a million lines of code in many languages

- Before Shake
  - Masses of really complex Makefiles, slow builds
  - Answer to any build error was “make clean”

- After Shake
  - Robust and fast builds (at least x2 faster)
  - Maintainable and extendable (at least x10 shorter)

Limitations/Disadvantages

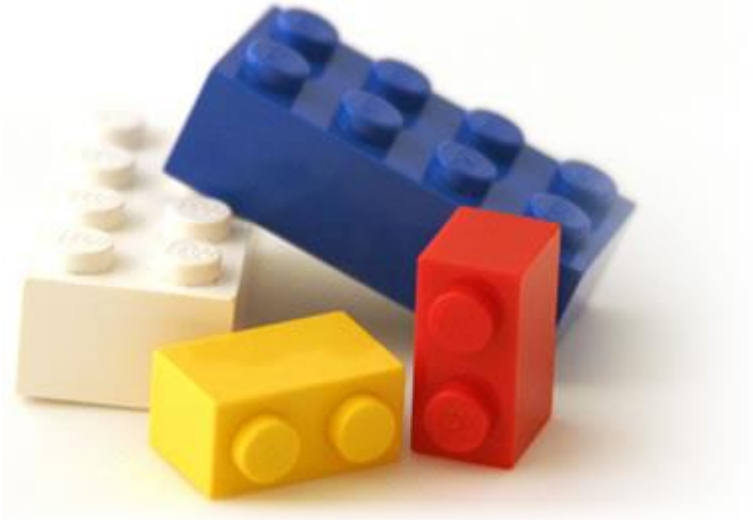
- Creates a _database file to save the database
- Oracle is currently “untyped” (String’s only)
  - Although easy to add nicely typed wrappers over it
- Massive space leak (~ 12% productivity)
  - In practice doesn’t really matter, and should be easy to fix
- More dependency analysis tools would be nice
  - Changing which file will cause most rebuilding?
- What if the rules change?
  - Can depend on Makefile.hs, but too imprecise

- Not currently open source

Shake Before Building

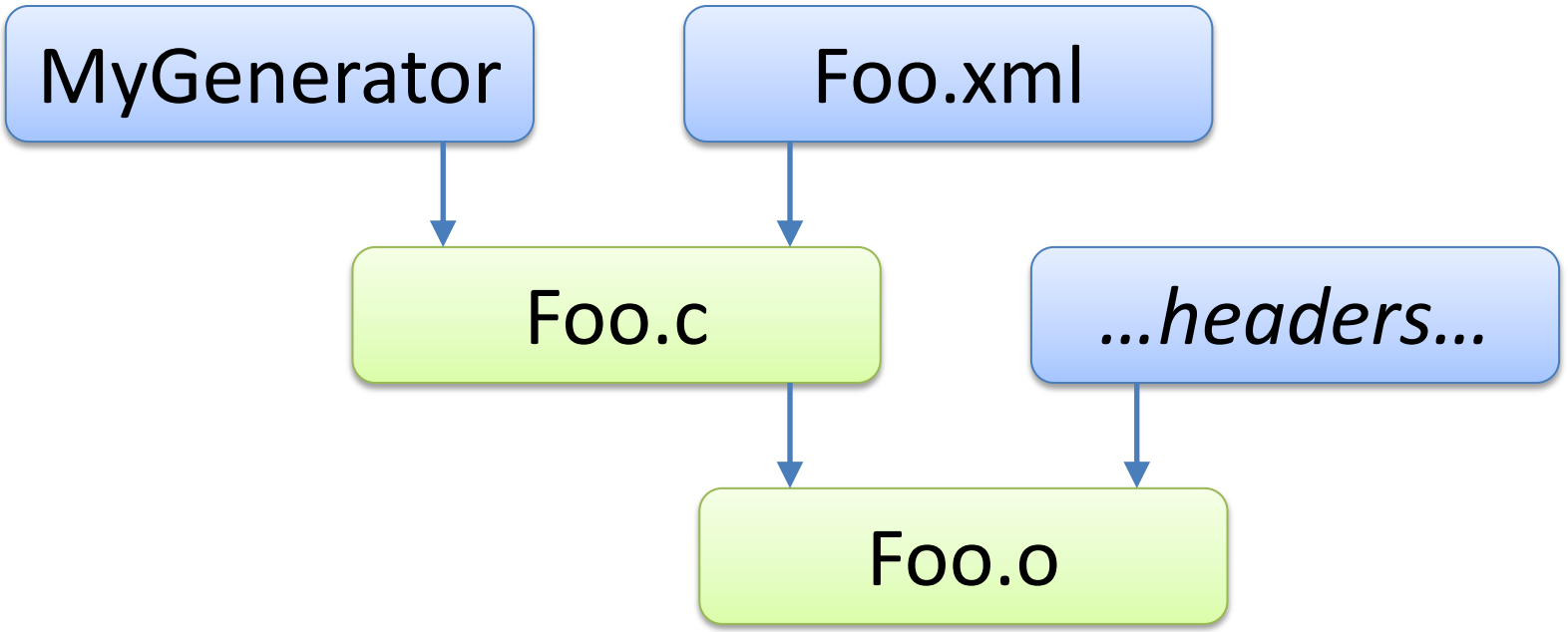
Replacing Make with Haskell

Neil Mitchell



community.haskell.org/~ndm/shake

Generated files



- What headers does Foo.c import?

  (Many bad answers, exactly one good answer)

Dependencies in Shake

```
"Foo.o" *> \_ -> do
  need ["Foo.c"]
  (stdout,_) <-
    systemOutput "gcc" ["-MM","Foo.c"]
  need $ drop 2 $ words stdout
  system' "gcc" ["-c","Foo.c"]
```

- Fairly direct
  - What about in make?

Make requires *phases*

```
Foo.o : Foo.c
    gcc –c Foo.o
```

```
Foo.o : $(shell sed … Foo.xml)
```

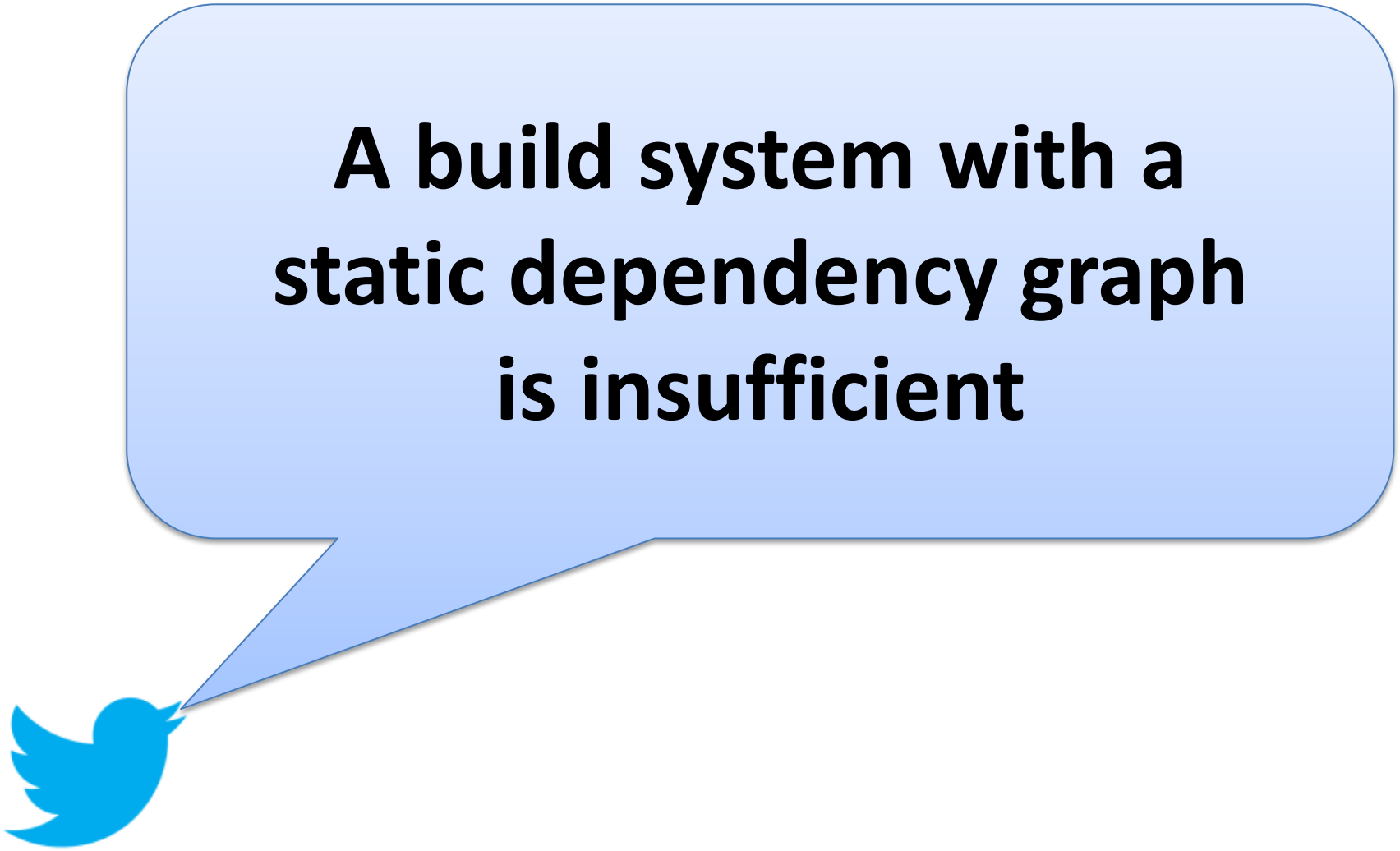
```
Foo.mk : Foo.c
    gcc –MM Foo.c > Foo.mk
#include Foo.mk
```

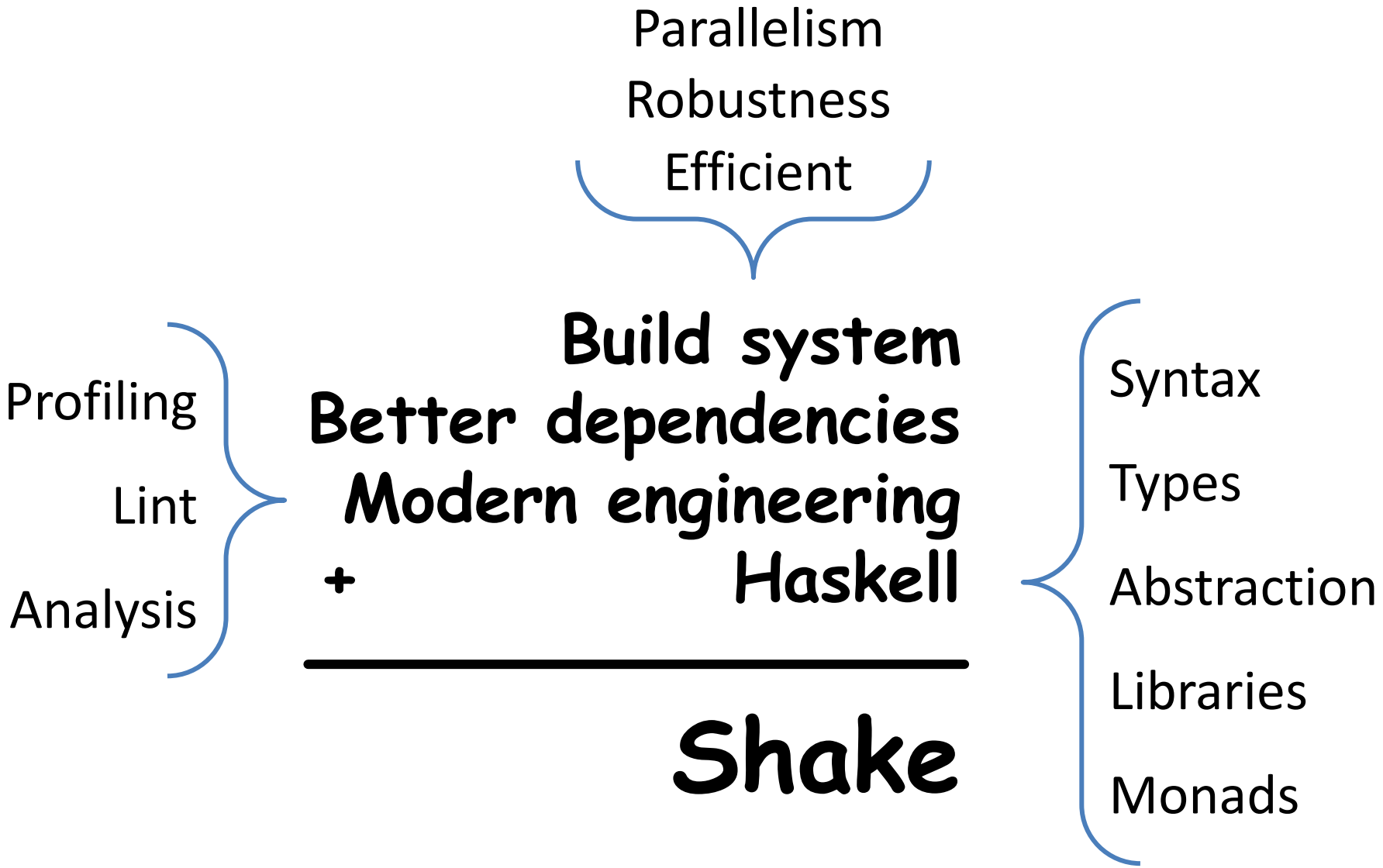
Disclaimer: make has hundreds of extensions, none of which form a consistent whole, but some can paper over a few cracks listed here

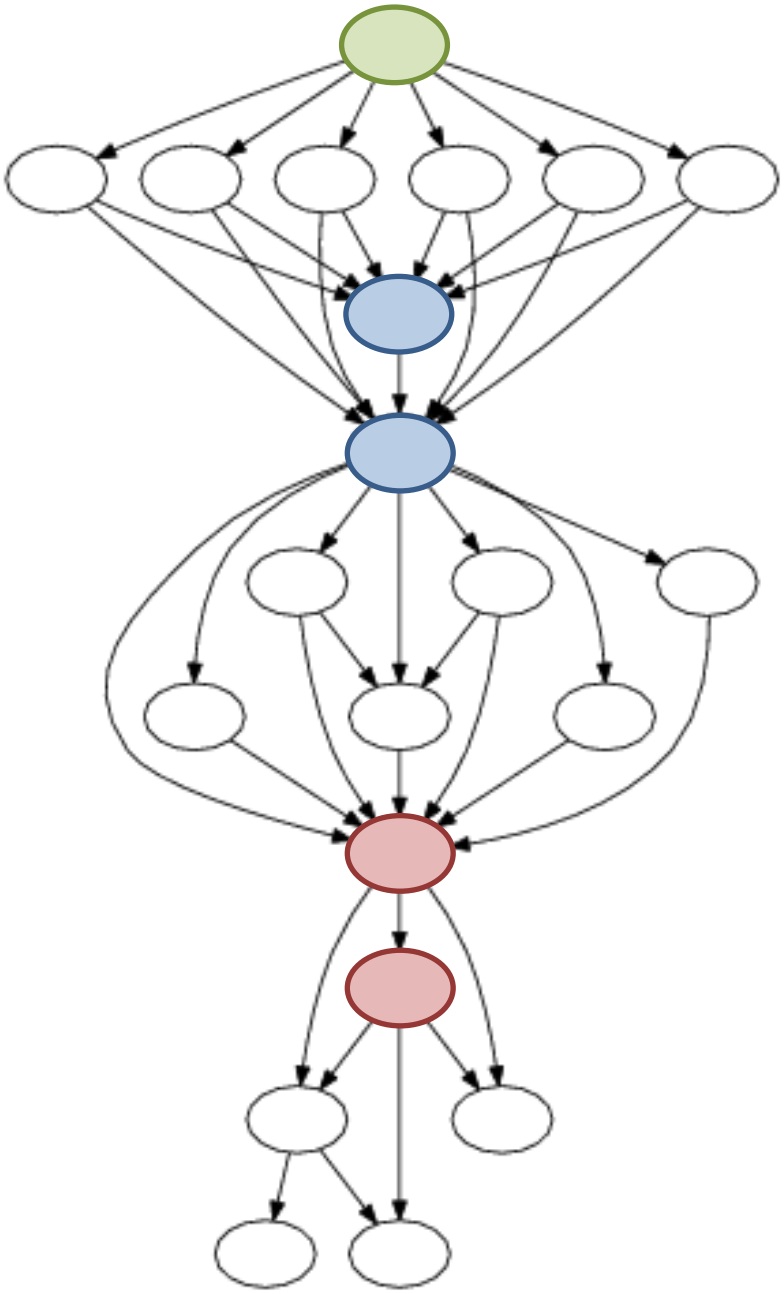
Dependency differences

- Make
  - Specify all dependencies *in advance*
  - Generate static dependency graph
- Shake
  - Specify additional dependencies *after* using the results of previous dependencies

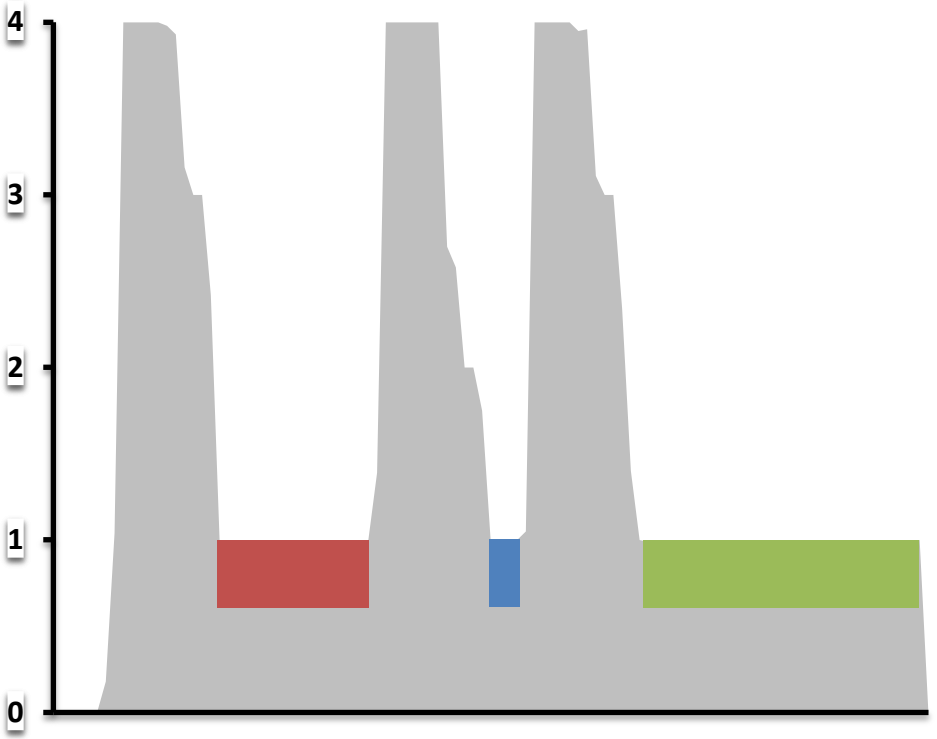
$$\mathbf{D}_{\text{shake}} > \mathbf{D}_{\text{make}}$$


A build system with a
static dependency graph
is insufficient


Parallelism
Robustness
Efficient
Profiling
Lint
Analysis
Build system
Better dependencies
Modern engineering
+
Haskell
Shake
Syntax
Types
Abstraction
Libraries
Monads



Profiling



Identical performance to make

Shake build system

Featureful, Robust, Fast

Haskell EDSL
Monadic
Polymorphic
Unchanging

1000's of tests
100's of users
Heavily used

Faster than
Ninja to
Build Ninja

Simple example

```
out : in
    cp in out
```

```
(%>) :: FilePattern -> (FilePath -> Action ()) -> Rule ()
```

```
"out" %> \out -> do
    need ["in"]
    cmd "cp in out"
```

:: Action ()
Monad Action

:: Rule ()
Monad Rule

Unchanging

- Assume you change whitespace in MyHeader.xml and MySource.c doesn't change
  - What rebuilds?
  - What do you want to rebuild?
  - (*Very* common for generated code)

Unchanging consequences

- Assume you change whitespace in MyHeader.xml
  - Using file hashes: MyGen.hs runs and nothing
  - Using modtimes: Stops if MyGen.hs checks for Eq first

- Always build children before their parents
- What if a child fails, but the parent changed to no longer require that child?
  - Must rebuild the parent and fail on demand

Polymorphic dependencies

- Can dependency track more than just files

```
"_build/run" <.> exe %> \out -> do
  link <- fromMaybe "" <$> getEnv
  "C_LINK_FLAGS"
  cs <- getDirectoryFiles "" ["//*.c"]
  let os = ["_build" </> c -<.> "o" | c <- cs]
  need os
  cmd "gcc -o" [out] link os
```

Polymorphic dependencies

- About 7 built in Rule instances

```
type ShakeValue a = (Show a, Typeable a, Eq a,
                     Hashable a, Binary a, NFData a)

class (ShakeValue k, ShakeValue v) => Rule k v where
    storedValue :: k -> IO (Maybe v)
```

Progress prediction

- Guesses how long the build will take
  - 3m12s more, is 82% complete
  - Based on historical measurements plus guesses
  - All scaled by a progress rate (guess at parallel setting)
  - An approximation…

Why is Shake fast?

- What does fast even mean?
  - Everything changed? Rebuild from scratch.
  - Nothing changed? Rebuild nothing.
- In practice, a blend, but optimise both extremes and you win

Fast when everything changes

- If everything changes, rule dominate (you hope)
- One rule: Start things *as soon as you can*
  - Dependencies should be fine grained
  - Start spawning before checking everything
  - Make use of multiple cores
  - Randomise the order of dependencies (~15% faster)
- Expressive dependencies, Continuation monad, cheap threads, immutable values (easy in Haskell)

Fast when nothing changes

- Don’t run users rules if you can avoid it
- Shake records a *journal*, [(k, v, …)]

```
unchanged journal = flip allM journal $ \(k,v) ->
  (== Just v) <$> storedValue k
```

- Avoid lots of locking/parallelism
  - Take a lock, check storedValue a lot
- Binary serialisation is a bottleneck

Non-recursive Make Considered Harmful: Build Systems at Scale

Andrey Mokhov, Neil Mitchell, Simon Peyton Jones, Simon Marlow

Haskell Symposium 2016

The GHC and the build system

Glasgow Haskell Compiler:

- **25** years old
- **100s** of contributors
- **10K+** source files
- **1M+** lines of Haskell code
- **3** GHC stages
- **18** build ways
- **27** build programs: alex, ar, gcc, ghc, ghc-pkg, happy, …

The current build system:

- Non-recursive **Make**
- **Fourth** major rewrite
- **200** makefiles
- **10K+** lines of code
- **3** build phases
- Highly user-customisable
- And it works! **But…**

The result of 25 years of development

```
$1/$2/build/%.$$($3_osuf) : $1/$4/%.hs $$(LAX_DEPS_FOLLOW) \
        $$$$($1_$2_HC_DEP) $$($1_$2_PKGDATA_DEP)
    $$(call cmd,$1_$2_HC) $$($1_$2_$3_ALL_HC_OPTS) -c $$< -o $$@ \
        $$(if $$(findstring YES,$$($1_$2_DYNAMIC_TOO)), \
        -dyno $$(addsuffix .$$(dyn_osuf),$$(basename $$@)))
    $$(call ohi-sanity-check,$1,$2,$3,$1/$2/build/$$*)
```

$19 per line!

Make uses a global namespace of mutable string variables

- Numbers, arrays, associative maps are encoded in strings
- No encapsulation and implementation hiding
- Variable references are spliced into Makefiles: avoid spaces/colons
- To expand a variable use **$**; to get **$** use **$$**; to get **$$** use **$$$$**…

There are other problems

1. A global namespace of mutable string variables
2. Dynamic dependencies
3. Build rules with multiple outputs
4. Concurrency reduction
5. Fine-grain dependencies
6. Computing command lines, *essential complexity*

} *Accidental complexity*

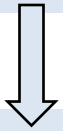
Solution: use FP to design scalable abstractions

- To solve **1-5**: we use **Shake**, a Haskell library for writing build systems
- To solve **6**: we develop a small EDSL for building command lines

Build rules with multiple outputs

```
"*.o" %> \obj -> do
    let src = obj -<.> "hs"
    need [src]
    run "ghc" [src]
```

How do we tell our build system that **ghc** produces both ***.o** and ***.hi** files?

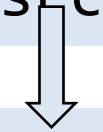


```
["*.o", "*.hi"] &%> \[obj, hi] -> do
    let src = obj -<.> "c"
    need [src]
    run "ghc" [src]
```

Concurrency reduction

```
"//*.conf" %> \conf -> do
    let src = confSrcFile conf
    need [src]
    run "ghc-pkg" ["update",
src]
```

But we can have at most one **ghc-pkg** running at a time as it mutates package db!



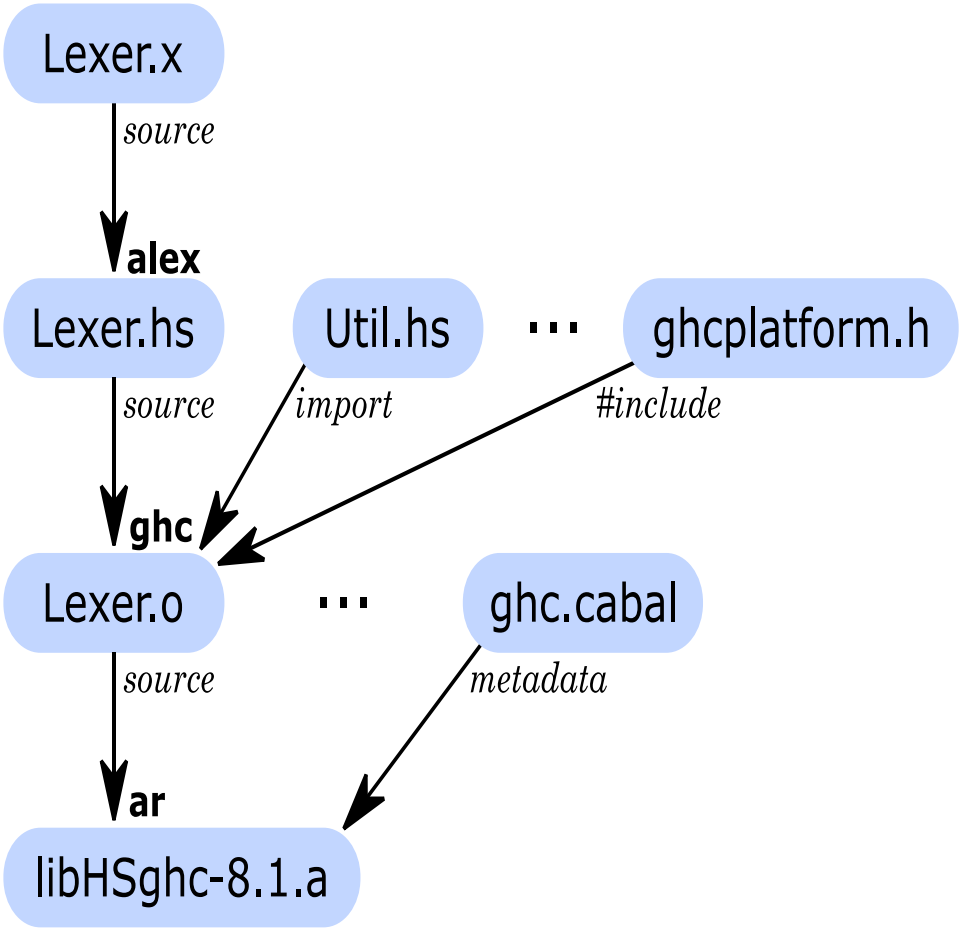
```
db <- newResource "package-db" 1

"//*.conf" %> \conf -> do
    let src = confSrcFile conf
    need [src]
    withResource db 1 $ run "ghc-pkg" ["update",
src]
```

Dynamic dependencies

Build target **t**:

- Lookup **t**'s dependencies $\{d_1, \ldots, d_n\}$ in the database
- **If** the lookup fails
  or **t** doesn't exist
  or **t** has changed
  or some d_k is not up to date
  then
  - Find the build rule matching **t**
  - Run the action, recording **need**'s
  - Update the database with newly recorded dependencies



More quick wins with Shake

Post-use dependencies

Order-only dependencies

Polymorphic/fine-grain dependencies

Tracking file contents

Avoiding external tools

…

Read the paper!

Target

Each invocation of a builder is fully described by a *target*

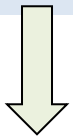
```
data Target = Target
    { context :: Context
    , builder :: Builder
    , inputs  :: [FilePath]
    , outputs :: [FilePath] }

preludeTarget = Target
    { context = Context Stage1 base profiling
    , builder = Ghc Stage1
    , inputs  = ["libraries/base/Prelude.hs"]
    , outputs =
["build/stage1/libraries/base/Prelude.p_o"] }
```

Computing command line for a target

Given **preludeTarget** how to compute the build command for it?

```
preludeTarget = Target
    { context = Context Stage1 base profiling
    , builder = Ghc Stage1
    , inputs  = ["libraries/base/Prelude.hs"]
    , outputs =
["build/stage1/libraries/base/Prelude.p_o"] }
```



```
commandLine :: Target -> Action [String]
```

```
inplace/bin/ghc-stage1 -O2 -prof -c
libraries/base/Prelude.hs

    -o build/stage1/libraries/base/Prelude.p_o
```

Expression

An *expression* **`Expr a`** is a computation that produces a value of type **`Action a`** and can read the current build **`Target`**:

```
type Expr a = ReaderT Target Action a

ghcArgs :: Expr [String]
ghcArgs = do
    target <- ask
    return $ [ "-O2" ]
           ++ [ "-prof" | way (context target)
== profiling ]
           ++ [ "-c", head (inputs  target) ]
           ++ [ "-o", head (outputs target) ]
```

Current limitations

We can build stage 2 GHC, but still lack many features:

- We only build `vanilla` and `profiling` way
- Validation is not implemented
- Only HTML Haddock documentation is supported
- Not all build flavours are not supported
- Cross-compilation is not implemented
- No support for installation or binary/source distribution
- 46 open issues: https://github.com/snowleopard/hadrian/issues

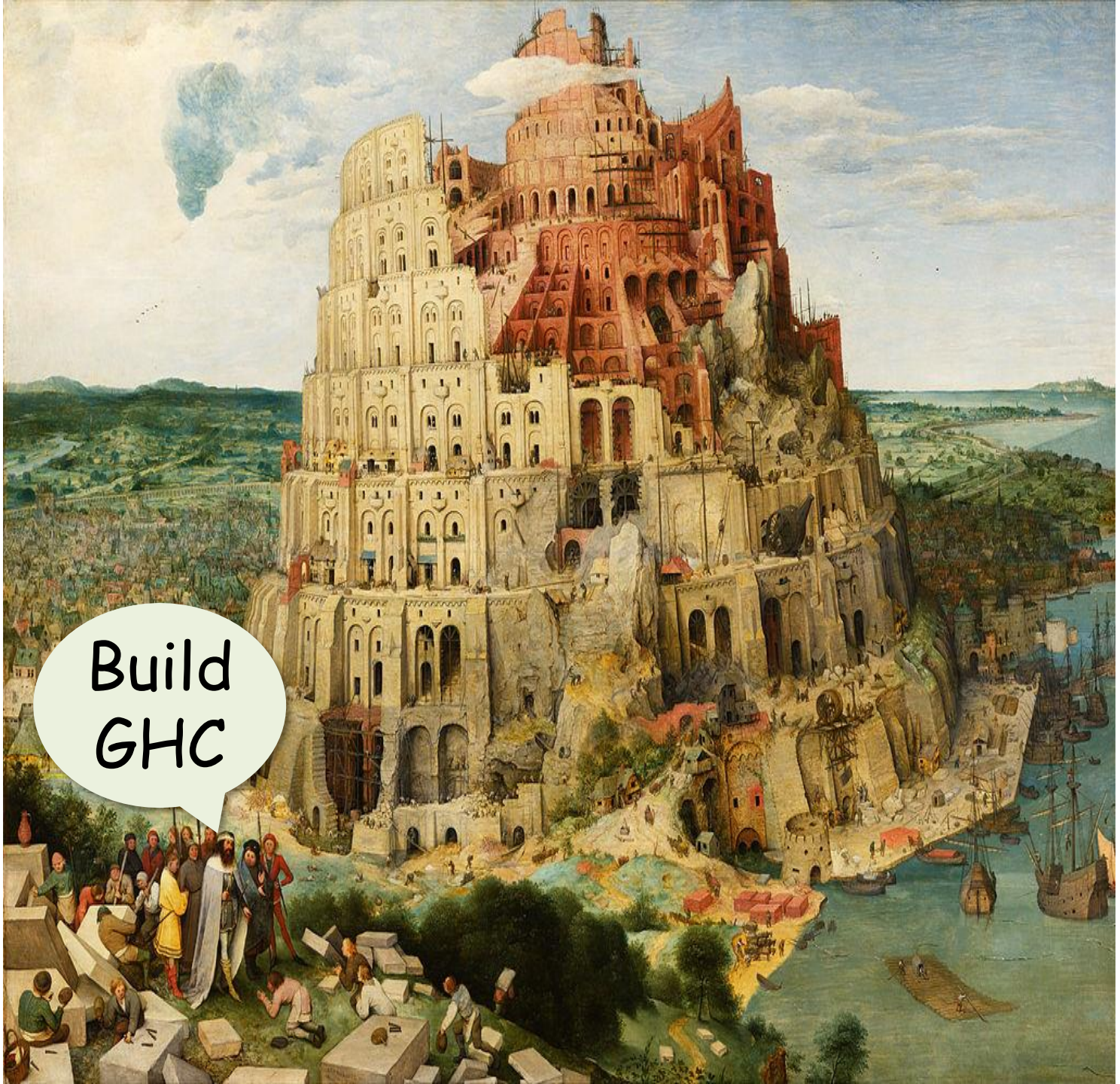
Experiments

Qualitative analysis:

- We studied 11 common use-cases of GHC build system, such as *"edit a source file and rebuild"*, *"add a new build command line argument and rebuild"*, *"git branch and rebuild"*, etc.
- The old build system performs a lot of unnecessary rebuilds in many cases, whereas Hadrian correctly handles most cases.

Quantitative benchmarks: Hadrian is faster

- Zero build: 2.2s vs 2.0s (Linux), 12.3s vs 2.1s (Windows)
- Full build: 649s vs 578s (Linux), 1266s vs 737s (Windows)


Build
GHC

Future directions – better API

- After 9 years, I'm still improving the API
  - Currently working on a rewrite for defining rule types
  - Makes rules faster and more powerful
  - Use type families to assert rule relationships

Future directions – tracing

- What if we could track every file accessed?
  - Lint checks
  - Automatic dependencies
- Requires cross-OS tracing primitives

Future directions – forward

```
import Development.Shake
import Development.Shake.Forward
import Development.Shake.FilePath

main = shakeArgsForward shakeOptions $ do
    contents <- readFileLines "result.txt"
    cache $ cmd "tar -cf result.tar" contents
```

Future directions – cloud

- “Towards Cloud Build Systems with Dynamic Dependency Graphs”
- Aka, Google scale, better dependencies
  - Compete with Bazel/Buck