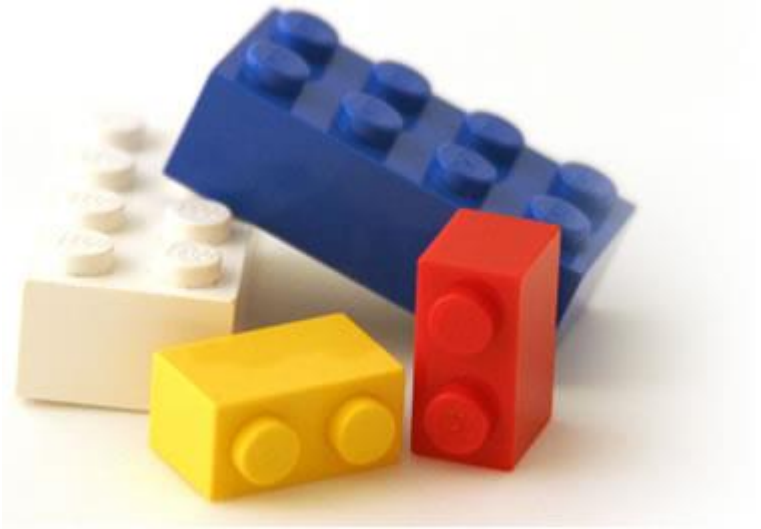
Distributed Build Systems



Neil Mitchell

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A simple build system

```
main.exe : main.o
    gcc -o main.exe main.o

main.o : main.c
    gcc -c main.c
```

Make, 1976

(42 years ago, 12BG)

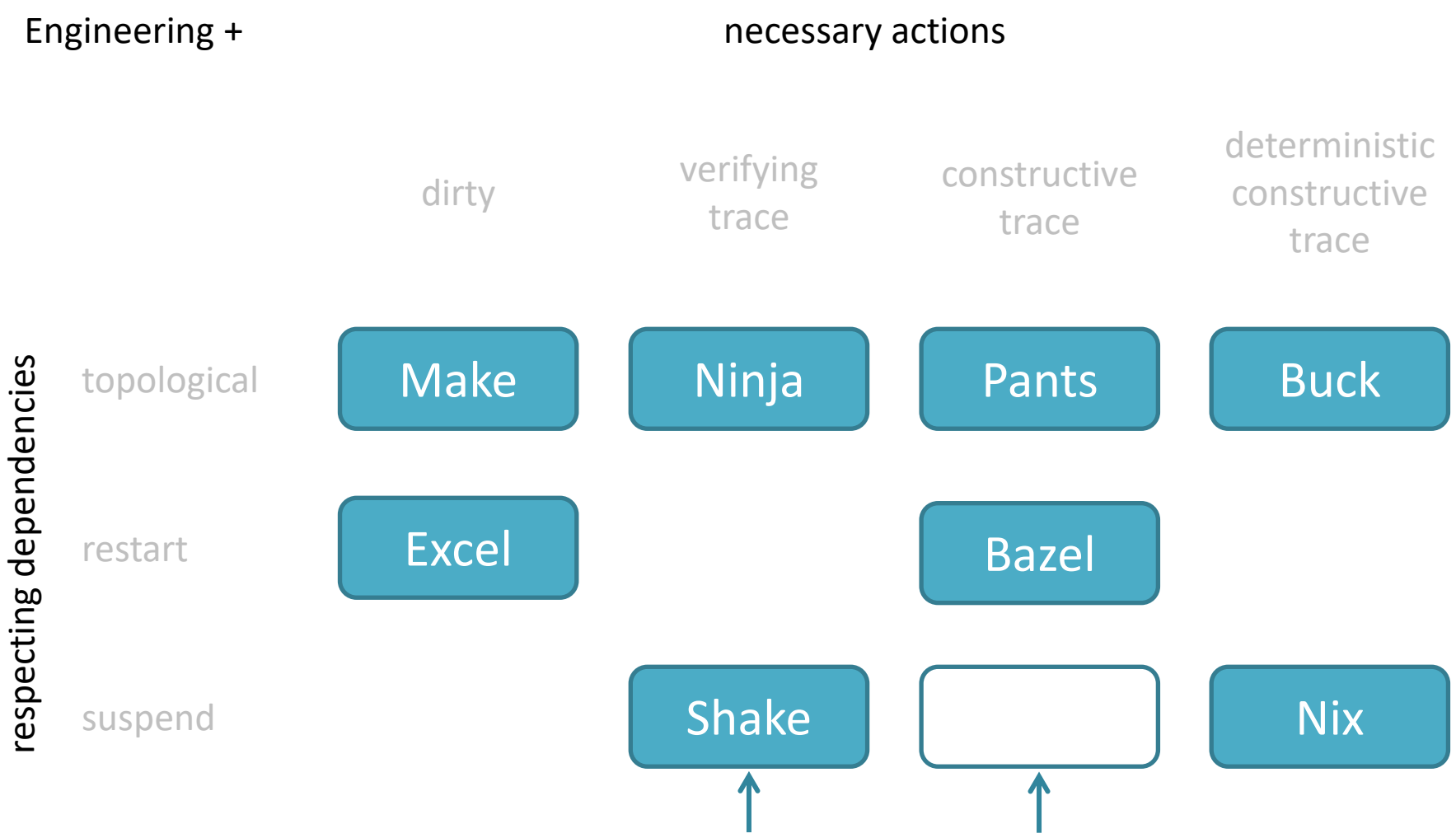
Build system definition

A build system performs necessary actions, respecting dependencies

We focus on general-purpose build systems

Build systems

Build Systems à la Carte



RESPECTING DEPENDENCIES

The order in which to execute tasks

- Topological
- Restart
- Suspend

“Monadic” dependencies

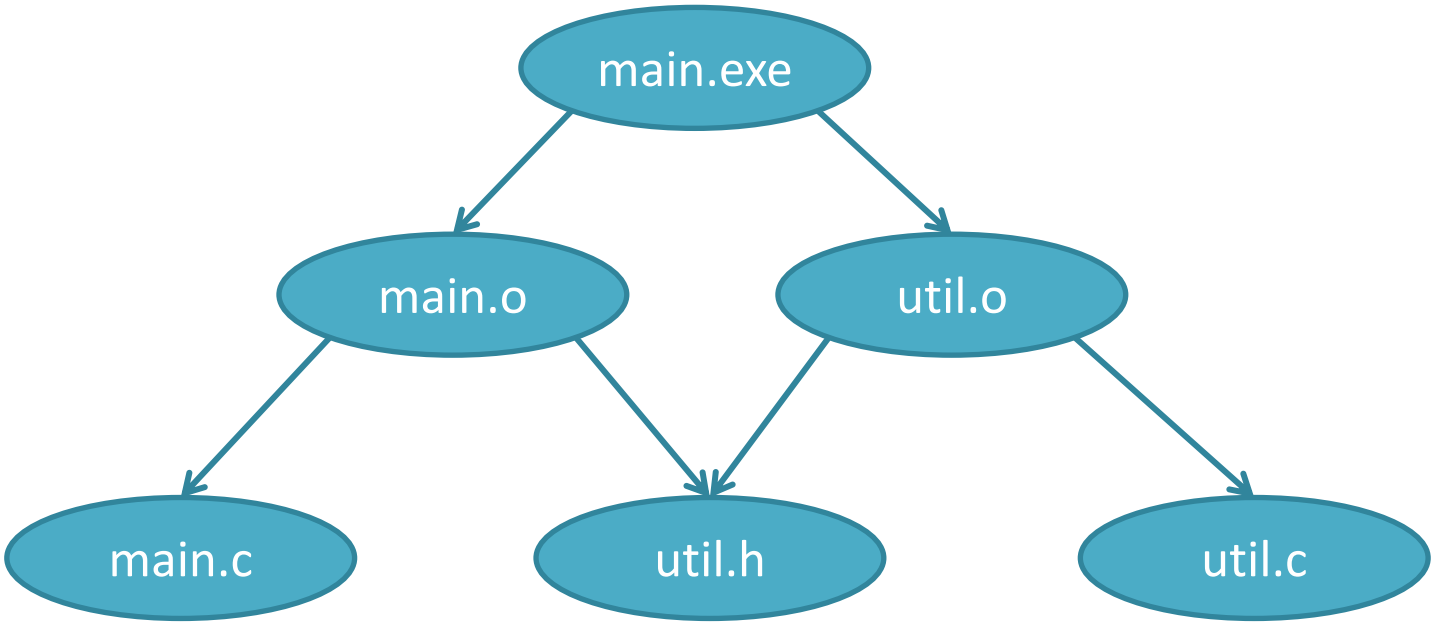
- When do I tell you my dependencies?
  - *Applicative*: Before doing anything, in advance
  - *Monadic*: Before I use them

```
main.o :
    need main.c                          ←
    need $(includes_of main.c)           ←
    gcc -c main.c


main.c : …
```

Topological

- Only works for Applicative dependencies
- Build a graph, traverse graph



Restart/Suspend

- Build a rule
- If it depends on a rule not yet built
  - Restart: Cancel this rule, schedule it last, build dep
  - Suspend: Pause this rule, build dep, resume

- Can you cancel or pause your rules?
- Pause requires more memory, but less work

Tricks for restarting

- Bazel
  - Use the applicative dependencies to part order
  - Doesn’t really allow user written monadic deps
- Excel
  - Keep a list of the order that worked last time
  - Consequence: Your sheet calcs faster over time!

Respecting dependencies

- Topological – Applicative only, easy
- Restart – May duplicate work
- Suspend – May be hard to orchestrate

Shake

- Shake’s raison d'être is monadic deps
- Uses continuations to efficiently suspend
  - First version used green threads

NECESSARY ACTIONS

I rebuilt this rule last time, should I do so again?

- Dirty
- Verifying trace
- Constructive trace
- Deterministic constructive trace

Dirty bit

A rule is dirty if anything it depends on is dirty

- Excel records it directly
- Make encodes dirty bit with relative modtimes
  - modtime(in) > modtime(out) = dirty
  - Cute trick: outputting a new result clears the bit, and propagates dirty bits upstream
- You need to know your deps, ~Applicative only

Verifying trace

A *trace* records the relevant bit of the state

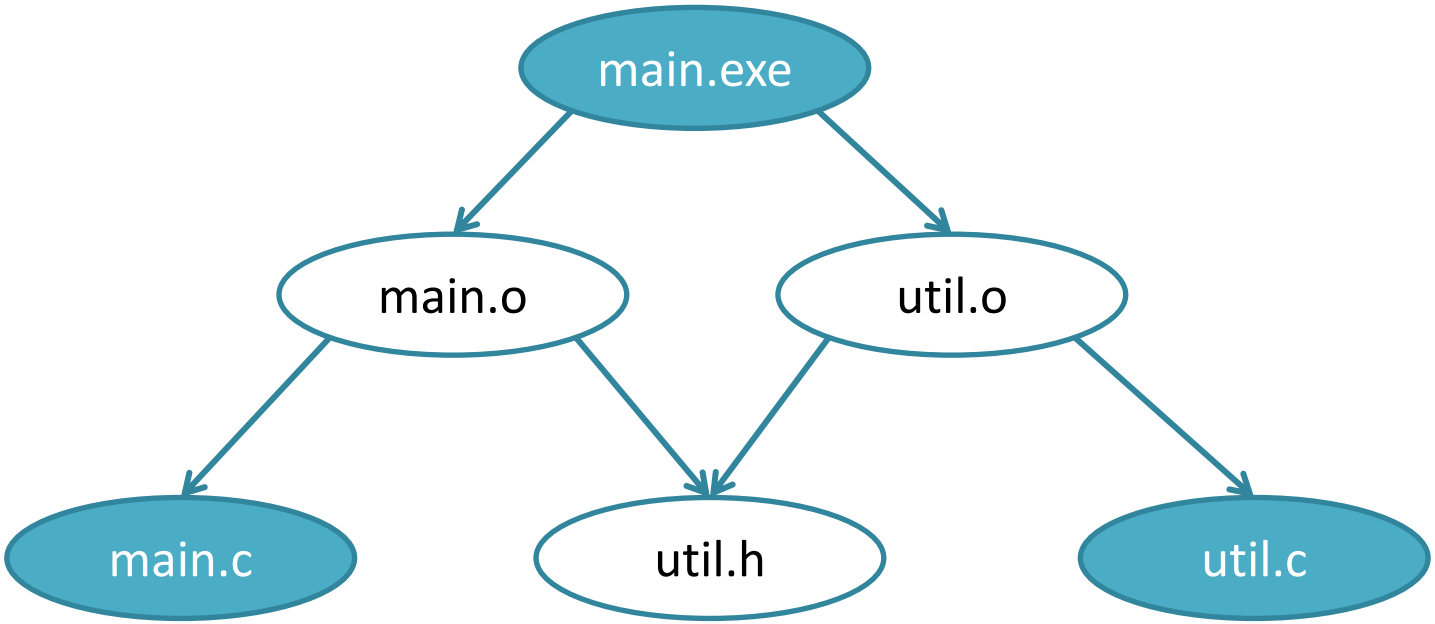
- What did I depend on last time?
- What were the values of those things?

main.o depends on main.c, which had hash 0x12

- If the trace matches, don’t rerun

Early cut-off

- What if I build but don't change?
- Possible with Dirty? Possible with Verifying?



Constructive traces

Aka “Cloud build” or “Distributed build systems”

- Record the output with the trace
- Shove all the traces on the server
- Now you can download already built stuff

Lots of engineering involved…

Deterministic constructive traces

Imagine the output of a rule depends only on its inputs (deterministic)

- Given the inputs, I can predict the value of any output, download the final answer
- Less round-trips to the server
- Doesn’t support cut-off

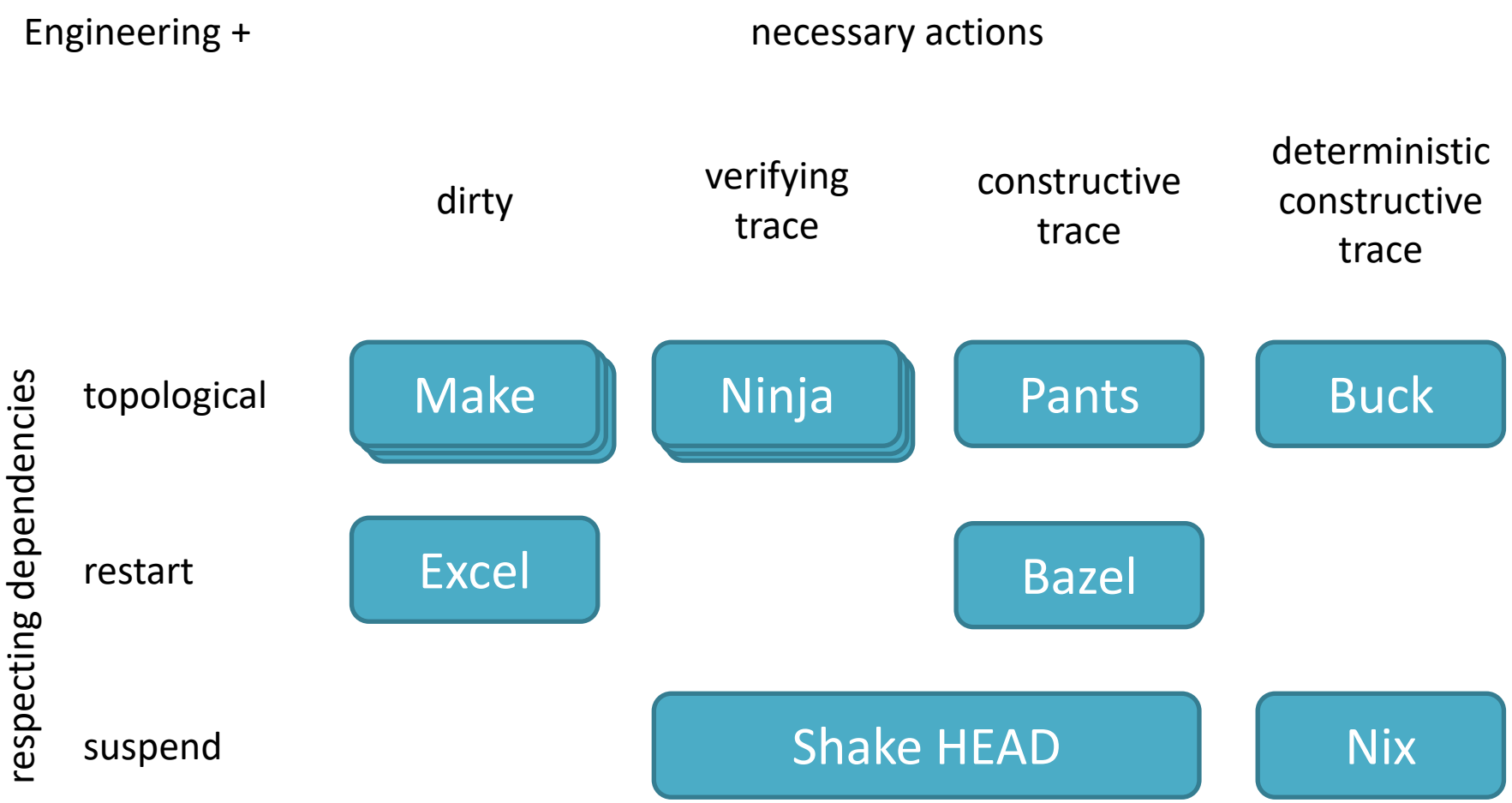
Necessary actions

- Dirty – ~Applicative only
- Verifying trace – local only
- Constructive trace
- Deterministic constructive trace – no cut-off

Shake

- Uses optimised verifying trace (two versions)

Build Systems à la Carte



Accepted to ICFP 2018 with Andrey Mokhov, Simon Peyton Jones

Engineering: Shake

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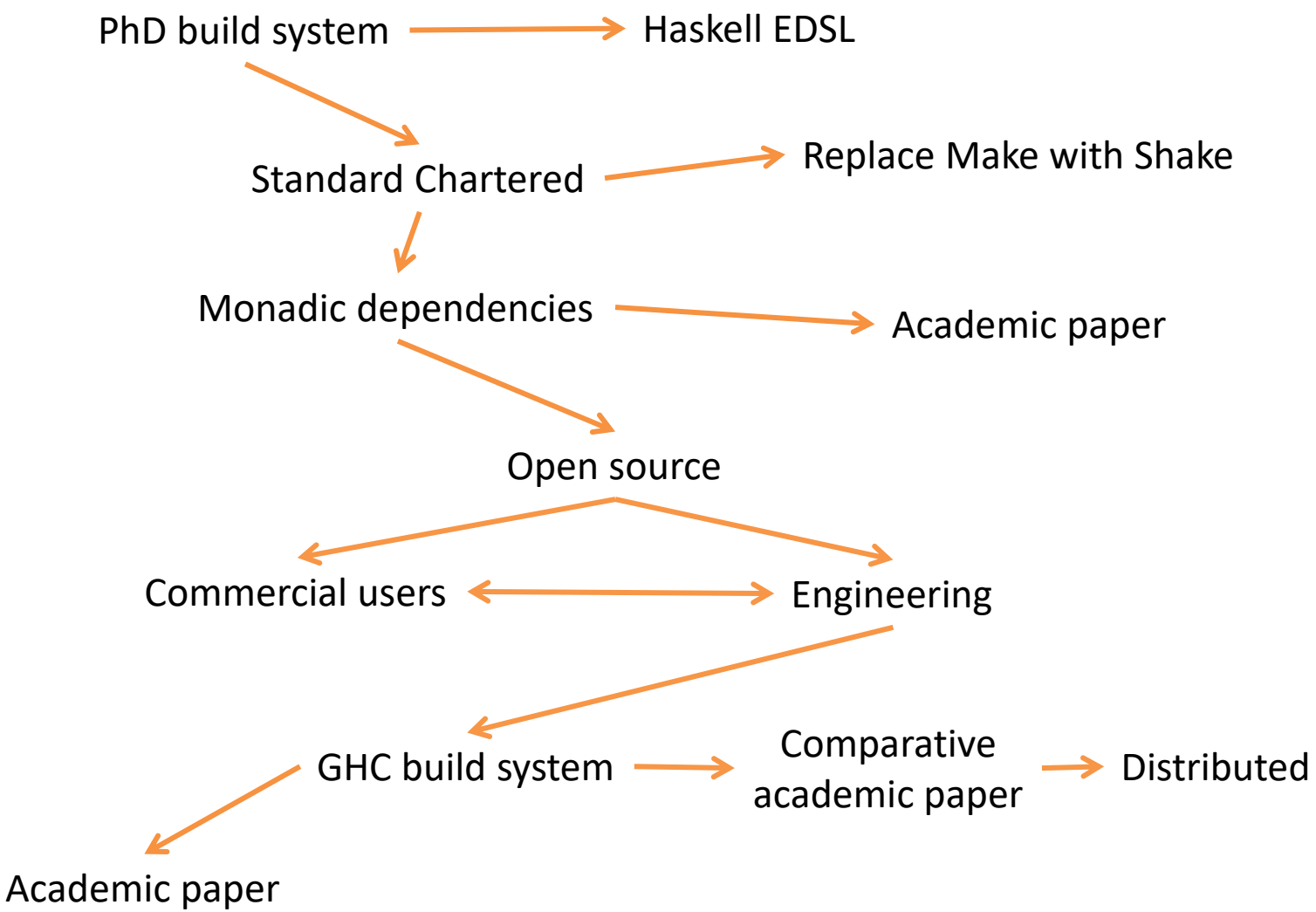
Rewind the clock



Papers with Andrey Mokhov, Simon Peyton Jones, Simon Marlow

Simple Shake

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

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

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

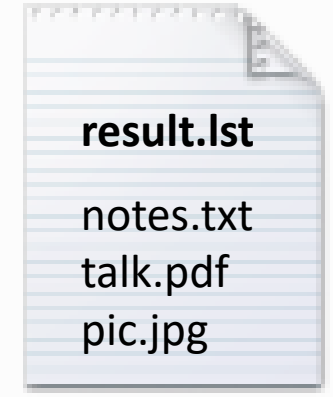
:: Action ()
Monad Action

:: Rule ()
Monad Rule

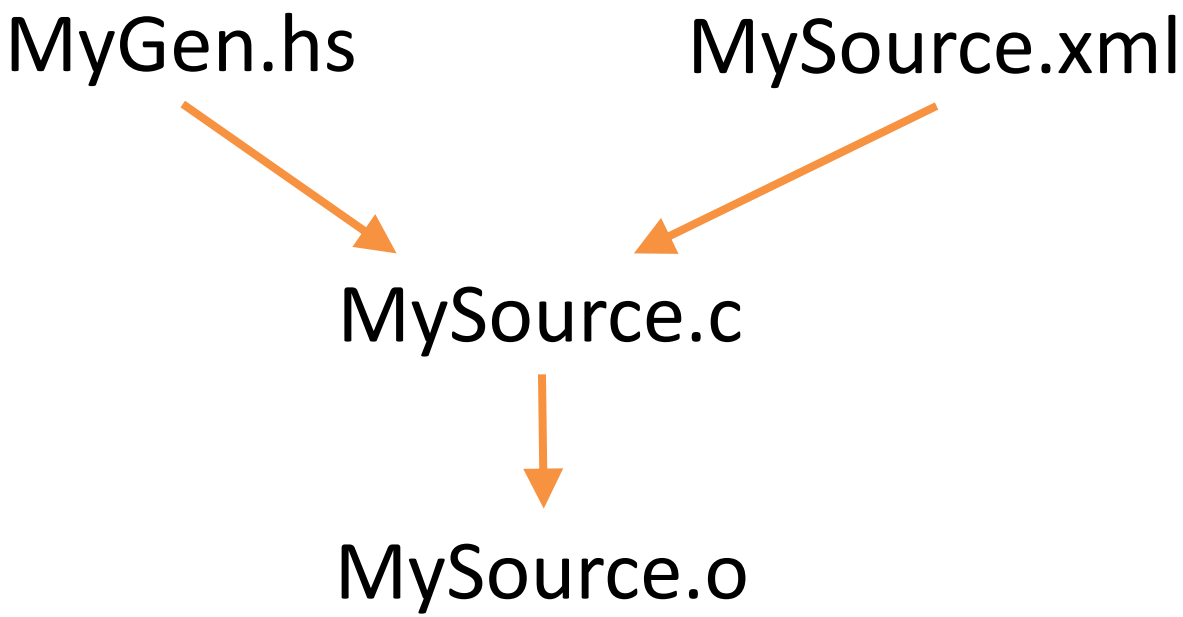
Longer example

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

main = shakeArgs shakeOptions $ do
    want ["result.tar"]
    "*.tar" %> \out -> do
        need [out -<.> "lst"]
        contents <- readFileLines $ out -<.> "lst"
        need contents
        cmd "tar -cf" [out] contents
```



Generated files



What does MySource.o depend on?

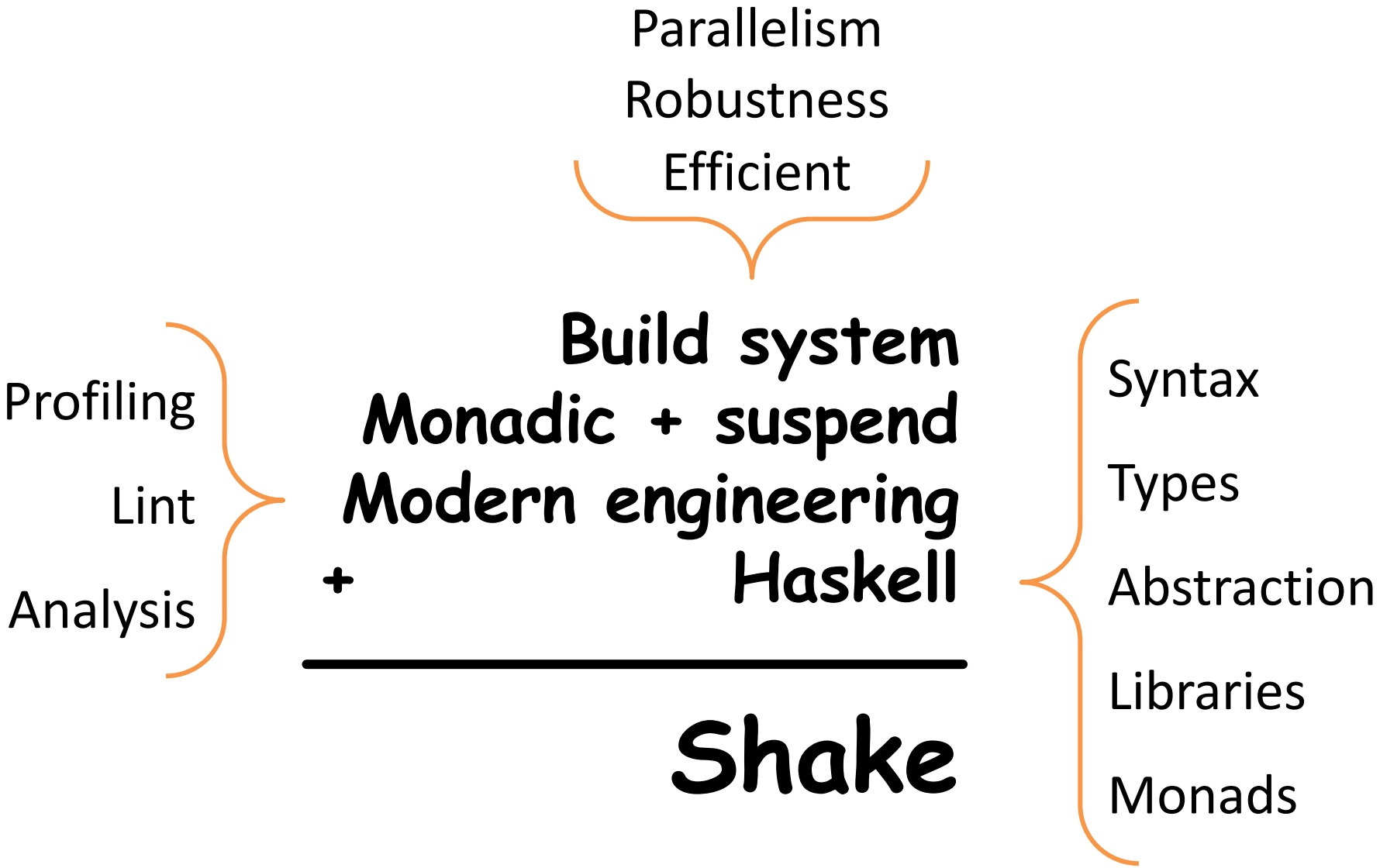
Generated approaches

- Hardcode it?
  - Very fragile.
- Hack an approximation of MyGen?
  - Slow, somewhat fragile, a lot of effort.
- Build in stages?
  - Non-compositional
- Run MyGen.hs and look at MySource.c
  - Easy, fast, precise. Use *monadic* dependencies.

Monadic is necessary

- If *any* rule needs monadic, you need it
  - Even if “rare” in your system
- Workarounds are not compositional
- Generated files cry out for monadic
  - Generated code is common in large projects

- Advice: Don’t use a non-monadic system


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

Shake at Standard Chartered (2012)

- In use for ~~three~~ nine years:
  - 1M+ build runs, 30K+ build objects, 1M+ lines source, 1M+ lines generated
- Replaced 10,000 lines of Makefile with 1,000 lines of Shake scripts
  - Twice as fast to compile from scratch
  - Massively more robust

Disclaimer: I used to be employed by Standard Chartered Bank. These slides do not represent the views of Standard Chartered.

Ready for primetime!

- **Standard Chartered** have been using Shake since 2009, 1000's of compiles per day.
- **factis research GmbH** use Shake to compile their Checkpad MED application.
- **Samplecount** have been using Shake since 2012, producing several open-source projects for working with Shake.
- **CovenantEyes** use Shake to build their Windows client.
- **Keystone Tower Systems** has a robotic welder with a Shake build system.
- **FP Complete** use Shake to build Docker images.

Don't write a build system unless you have to!

Stealing from Haskell

- Syntax, reasonable DSLs
- Some use of the type system (not heavy)
- Abstraction, functions/modules/packages
- Profiling the Haskell functions

Extra features

- HTML profile reports
- Very multithreaded
- Progress reporting
- Reports of live files
- Lint reports
- …

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 nothing changes

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

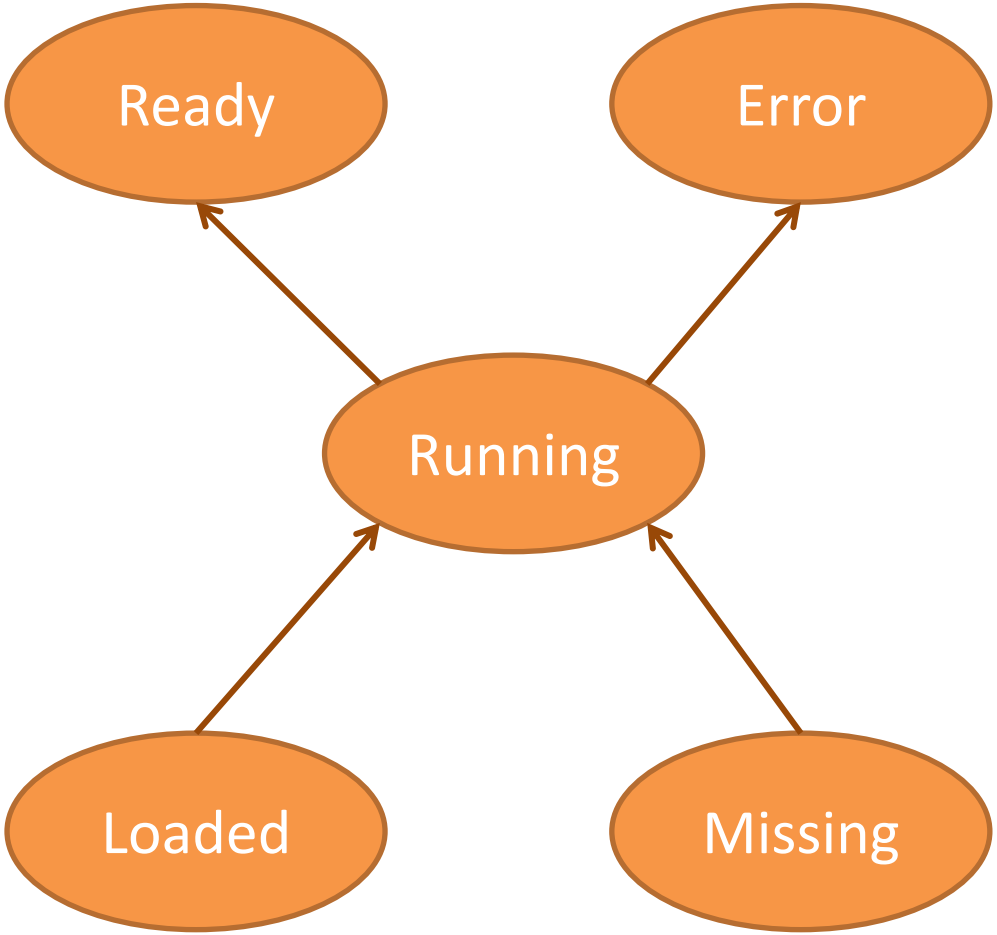
```
unchanged journal = flip allM journal $ \(k,v) ->
  (== Just v) <$> storedValue k
```

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

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)

State changes



Inside “Running”

- Build all my dependencies from last time
  - If any changed, then dirty
- Look at my result from last time
  - If it has changed, then dirty
- If dirty, see if I’m in the constructive trace
  - If I am, copy the result into my trace
- If still dirty
  - Run the user supplied action

Efficient suspend

- Continuations are mind-blowing (still)

```
a
(a -> r) -> r
```

- a = I get given ‘a’ now
- (a -> r) -> r = I get given ‘a’ later
- Covariant/contravariant equivalence
- Efficiently pause a running computation

Efficient resume

- Resumption is restarting suspended things

```
data Status
    = Running [Either Error Ready -> IO ()]
    | …
```

- Resume everything when changing status
  - Resumption is required to be “quick”
  - Therefore most resumption adds to the Pool...

Efficient parallelism

- A thread pool

```
addPool :: Pool -> PoolPriority -> IO () -> IO ()
```

- Not to reduce thread overhead
  - Haskell threads are super cheap
- To limit parallelism, and cleanup/finish

Efficient journaling

- Shake needs to record the verifying traces
  - Recorded in .shake.database
- A linear record of traces
  - Append to the end
  - Size prefixed to detect corruption
  - Compact if < ½ the values still useful
  - Flush every 5s

Conclusions

- Build systems make three choices:
  - Respecting dependencies
  - Necessary actions
  - Engineering choices
- Shake occupies an interesting spot
  - Plenty of engineering required to make it work