Evolving Fortran types with inferred units-of-measure

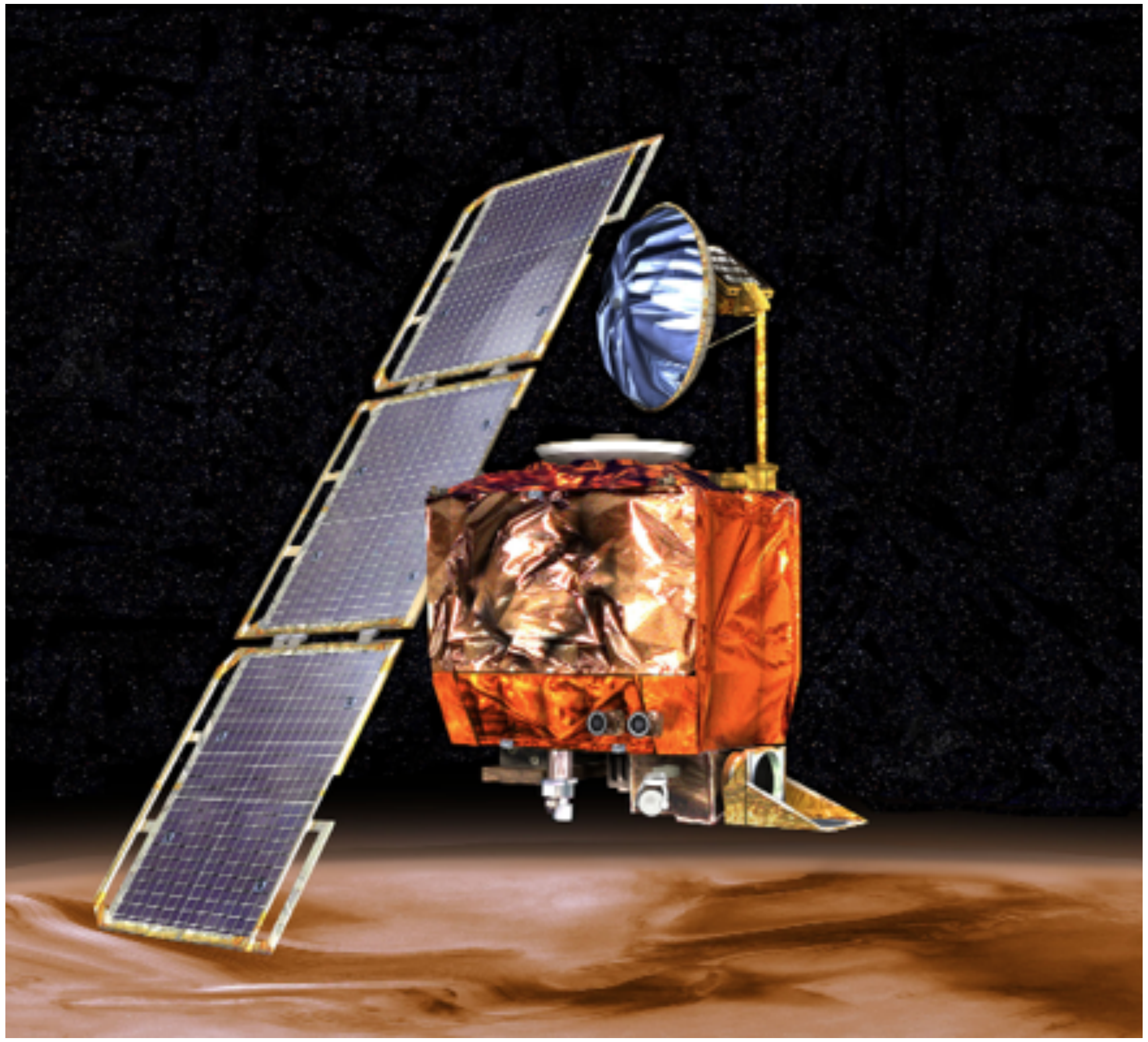
Dominic Orchard†, Andrew Rice*, Oleg Oshmyan

† Imperial College London

* UNIVERSITY OF CAMBRIDGE

dorchard.co.uk

ICCS 2015



Mars Climate Orbiter

September 23rd, 1999

Orbital insertion (artist's impression)

due to a unit mismatch:
foot-pounds (lbf) vs. Newtons (N)

$327.6 million

What actually happened….
(also artist's impression)

NASA/JPL/Corby Waste

Dimensional analysis

("Great Principle of Similitude", Isaac Newton, 1686)

x is a length (dimension)
x is in metres (unit of measure)

unit(`x * y`) = (unit `x`) * (unit `y`)

unit(`x / y`) = (unit `x`) / (unit `y`)

unit(`x + y`) = unit `x` = unit `y`

unit(`x - y`) = unit `x` = unit `y`

unit(`x^R`) = unit(`x`)^`R`

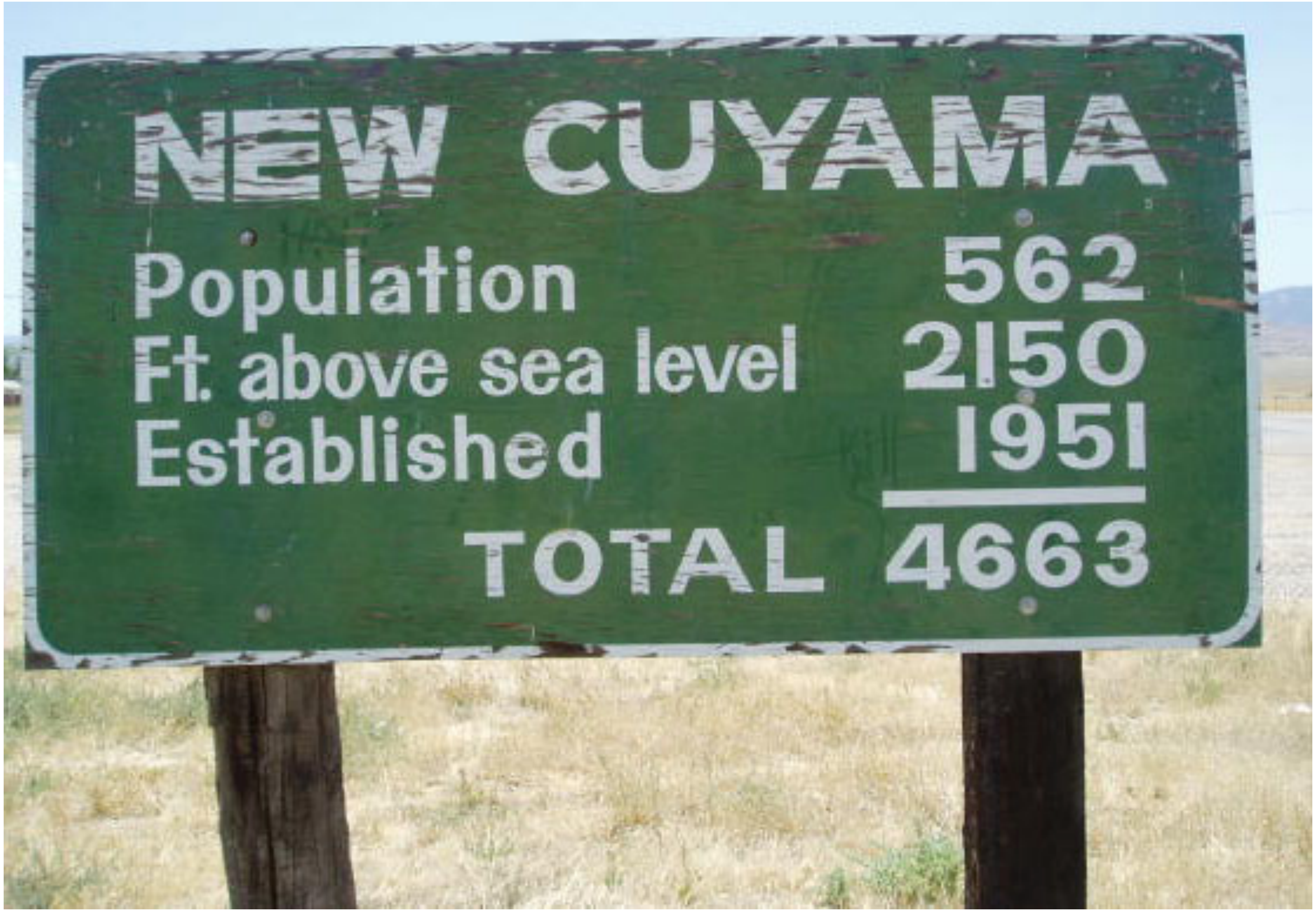


photo from Andrew Kennedy's website
http://research.microsoft.com/en-us/um/people/akenn/units/

Dimensional analysis = *a type sytem*

- House, 1983

  "A proposal for an extended form of type checking of expressions"

- Kennedy, 1994

  "Dimension Types"

- How many (popular) languages have this today?

  F#, Haskell [experimental], C [via extensions]

Fortran - an important target

- Fortran very popular in science
- Evolved considerably over 60 years
- Lots of long-running projects
- Many numerical programs
- A serious need for more verification*

Automatic tools to the rescue!!!

*A computational science agenda for programming language research, Orchard, Rice, ICCS 2014

A recent ISO proposal for Fortran units

```
unit :: m, s
unit :: mps = m / s
real, unit(m) :: x
real, unit(s) :: t
real, unit(mps):: v
real, unit(mps) :: s
...
v = x / t
s = abs(v)
```

Follows Fortran tradition of **explicit types**

- All units must be declared
- All variables must have a unit
- All derived units must have a unique name

ftp://ftp.nag.co.uk/sc22wg5/N1951-N2000/N1969.pdf

‘Explicitness’ tradition hinders evolution

- Two long-running climate modelling projects at Cambridge:
  - (Hybrid 8) 10kloc, 1k variable declarations
  - (Hybrid 4) 8.5kloc,1.2k variable declarations

Proposal: a lightweight approach

- Type inference
- Implicitly-introduced unit names
- Polymorphism

$$\texttt{abs} : \; \forall \mathrm{u}.\; \mathit{real},\; \mathit{unit}(\mathrm{u}) \rightarrow \; \mathit{real},\; \mathit{unit}(\mathrm{u})$$

- <u>Aid adoption</u> by suggesting annotation points

[critical variable analysis]

Demo time

CamFort tool…

- Cambridge Fortran research infrastructure [a pre-processor]
- Program analyses, transformations, refactorings

Upgrading Fortran source code using automatic refactoring, Orchard, Rice, WRT'13

- Type-system extensions (e.g., units-of-measure)

…& project at Cambridge

- (Semi)automated verification and testing
- Integrate with existing working practises
- More **sustainable** code

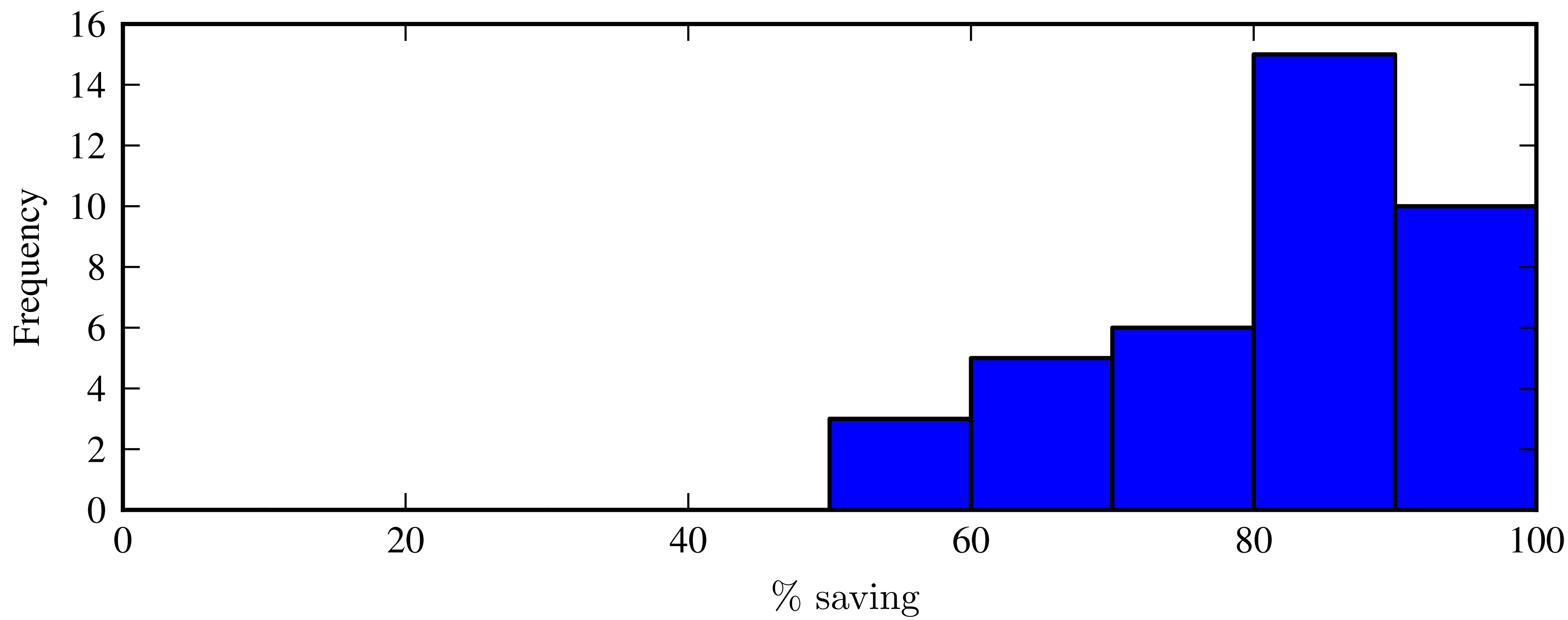
A computational science agenda for programming language research, Orchard, Rice, ICCS 2014

Evaluation

- 43 programs from *An Introduction to Computational Physics, Tao Pang, Cambridge University Press, 2006.*
- 50-200 lines in size
- Excluded 6 programs due to MPI or odd syntax

Evaluation - effort saving

$$\% \text{ saving} = \left(1 - \frac{\text{size of critical variable set}}{\text{number of variables}}\right) \times 100$$

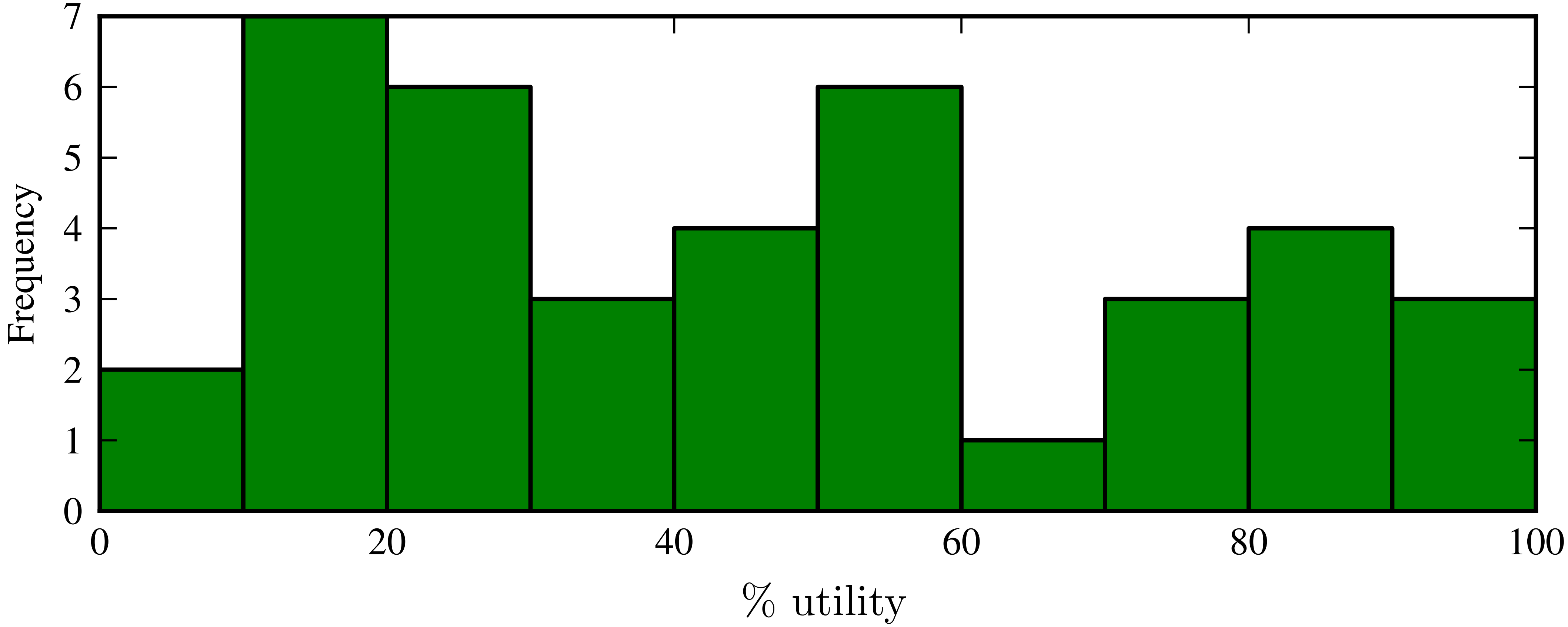


Median effort saving = 82.4% (3sf.)

Evaluation - utility of units

manually (as a critical variable) or after inference

$$\% \text{ utility} = \frac{\text{variables assigned a non-unitless unit}}{\text{number of variables}} \times 100$$



Median utility = 42.8% (3sf.)

Lessons learned...

- Automatic verification tools are good
  - Inference eases evolution, reduces effort (~ 82% saving)
- Breaking traditions can be good (when they hinder upgrading a code base)
- Units of measure are really worth it!

Download info + tutorial: http://dorchard.co.uk/units

See more: http://dorchard.co.uk/science

Thanks!