The role of proofs in computer science research

Paige Randall North

Utrecht University

March 13, 2026

Curry-Howard correspondence

(Constructive) mathematics	$\leftrightarrow$	(Functional) programming
Proofs	$\leftrightarrow$	Programs
Statements	$\leftrightarrow$	Program specifications

Curry-Howard correspondence

Example

Statement: For every natural number n, there is another natural number p which is prime and greater than n.

Proof: ...

Types

Haskell

We have types and type formers:

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- $\mathbb{L}\mathsf{ist}(A)$
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- You can only prove that externally.

Software verification

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- test it
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  - externally
    - Hoare logic
    - model checking
  - internally
    - type theory: a programming language with extra features so that you can prove things

Software verification

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- The correct-by-construction program is often not efficient
  - In practice (industry), two programs are sometimes created: an efficient one and a correct one

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- We introduce another type former $\Pi_{a,b::\mathbb{N}}\ a + b = b + a$

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- It is the type of functions that take in values $a, b :: \mathbb{N}$ and return some value in $a + b = b + a$, so in some languages you write

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- We call this a type of 'dependent functions'

Dependent pairs

Now consider the statement:

For every natural number n, there is another number p which is prime and greater than n.

- $isPrime(p) :=$
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- Now we can write $\Pi_{n::\mathbb{N}}\ \Sigma_{p::\mathbb{N}}\ isPrime(p) \times (p > n)$
- A value of this type is a program that produce a p from an n together with a proof that it is prime and bigger than n

Role of this verification

- Used increasingly in industry
  - Mostly on very critical and fundamental software/hardware
  - Supported by governments/militaries or in research groups
  - Very costly
- Automated theorem proving helps
- Gaining importance in mathematics

Current research

What does current research look like?

- Introducing the identity type creates interesting behavior $\rightarrow$ homotopy type theory
- Domain specific languages that verify specific programs/systems

- Implement these languages (normalization proofs/algorithms)
- Papers in this field are often ‘math papers’ (i.e. Definition - Theorem - Proof) but are often accompanied by code – the formalized proofs

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Thank you!