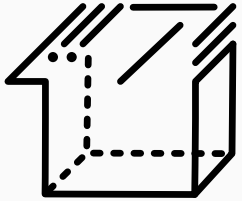
Towards Computational UIP in Cubical Agda

or: making proof assistants nicer to use by **filling squares**!



Yee-Jian Tan (j.w.w. Andreas Nuyts, Dominique Devriese)

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16 March 2026

Why Proof Assistants Matter?

Proof assistants (e.g. Agda  , Rocq  , Lean ) verify mathematical proofs.

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- 🛡️ **RustCompCert** [Wu+26] — (ongoing, 2026) — end-to-end verified Rust compiler, including a verified borrow checker.

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Assumes the **univalence axiom**: equivalent (isomorphic) types are equal. (If they behave exactly the same way, they must be equal). Buy 1 free 2!

Implemented in Agda as **Cubical Agda**.  Univalence derived from **Glue** types.

~~*Homotopy Type Theory*~~

Let's do **paths** and **squares** and **cubes**!  [1]

[1] [Coh+17]

Equality as paths: geometric interpretation

Type : a space

Terms : points in that space

Equality proof : a path between points

An example in natural numbers $\mathbb{N}$:

$\mathbb{N}$ is a space: $0, 1, 2, \ldots$ are its points.

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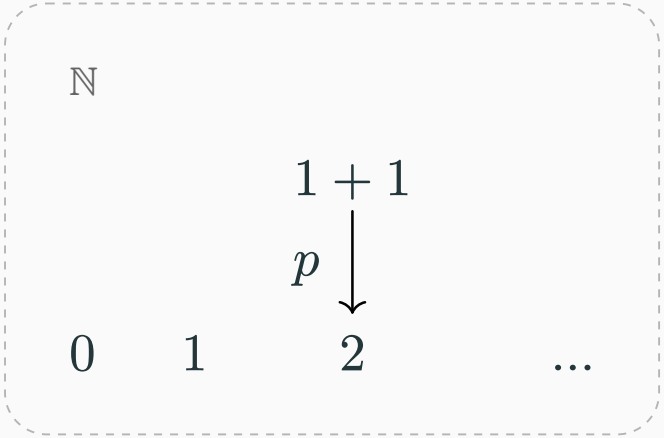

An example in natural numbers $\mathbb{N}$:

A proof that $1+1=2$ is a path $1+1 \xrightarrow{p} 2$ in $\mathbb{N}$.[1]

Reversing p gives you $2=1+1$ (symmetry).

[1] $\mathbb{N}$ is actually a **set** (h-set): all paths are refl, and $1+1$, 2, $2+0$ are the same point. Shown as distinct here for illustration only.

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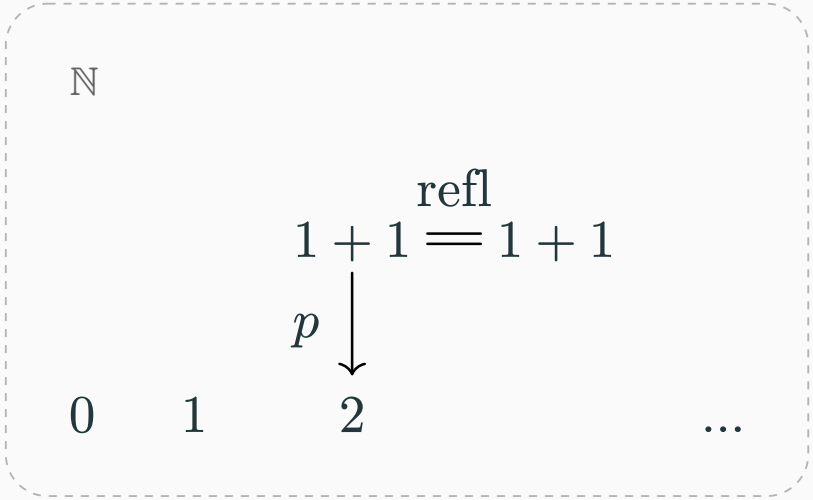
An example in natural numbers $\mathbb{N}$:

What about $1 + 1 = 1 + 1$? That is the constant path, $\mathbf{refl}$ (reflexivity).



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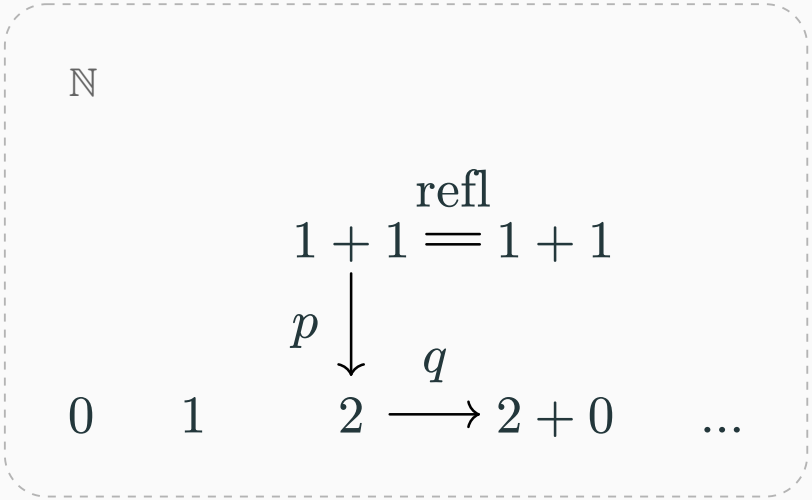

An example in natural numbers $\mathbb{N}$:

In Cubical Agda, you can compose 3[1] paths:

- $p : 1 + 1 = 2$ and
- $q : 2 = 2 + 0$ and
- $\mathrm{refl} : 1 + 1 = 1 + 1$

give

[1] Guess why it's called **Cubical**!

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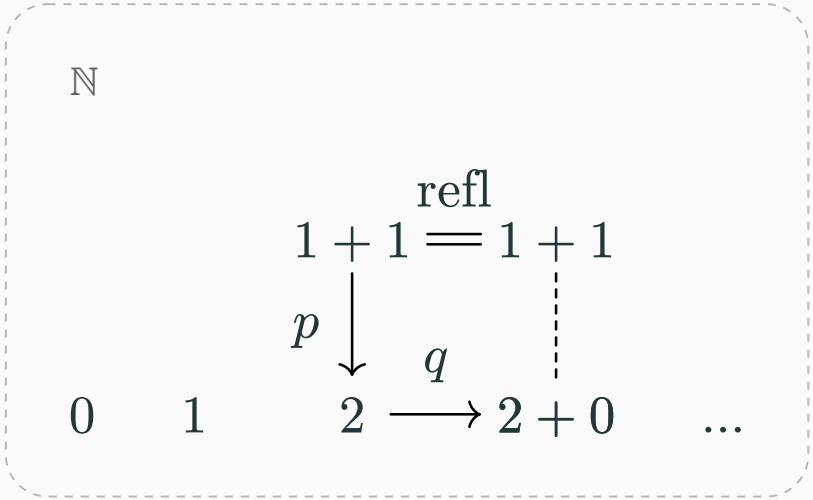

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$$q \cdot p \cdot \mathrm{refl} : 1 + 1 = 2 + 0.$$

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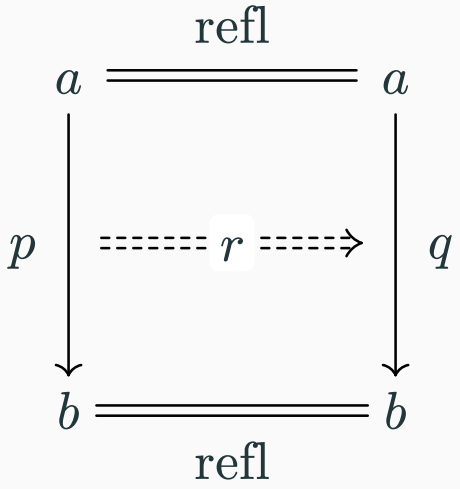

Observation

For an arbritraty type A, two paths $p, q : a =_A b$ can themselves be **equal**: witnessed by a **square**.

Squares can be equal too: then it becomes... a **cube**!

And **cubes** can be equal too... (you get the idea)

UIP and Square-Filling

In general, two paths $p, q : a = b$ need not be equal, but many structures (e.g. $\mathbb{N}$, $\mathbb{Z}$) are like sets: paths are always unique. (Easier!)

Uniqueness of Identity Proofs (UIP) condition

"There is at most one proof of $x =_A y$ for any $x\ y : A$."

Incompatible with one key ingredient of HoTT: **univalence**!

Fortunately compatible with Cubical Agda without *Glue* types: the source of **univalence** in Cubical Agda. We implemented a `--cubical=no-glue` variant of Agda [Tan25].

Geometrically:

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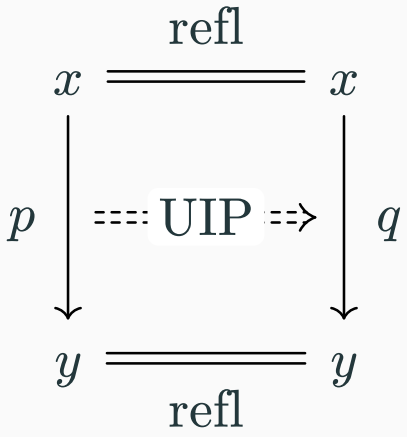

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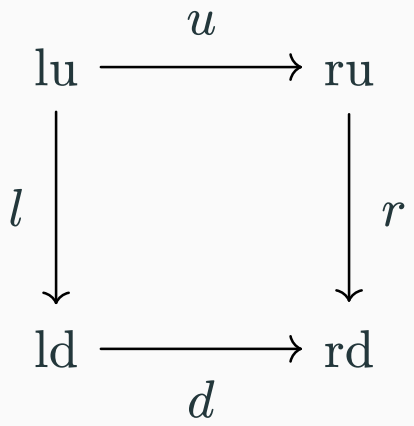
Square-Filling (SqFill): relax the refl conditions: **any** square has a filling.



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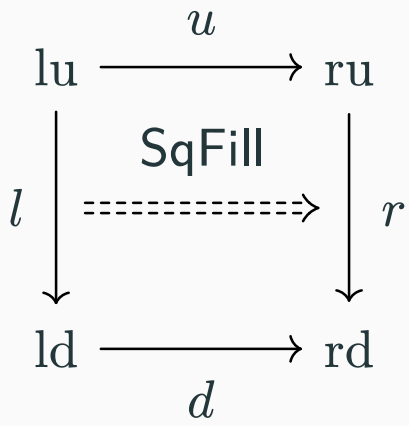

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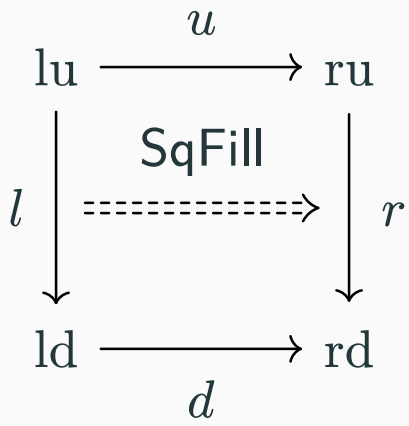

Surprisingly: UIP $\leftrightarrow$ SqFill are **equivalent**, but SqFill is easier to work with!

Genius idea 💡: just add in **SqFill** everywhere!

⚠️ Bad news: SqFill doesn't compute (naively)

Naïvely adding **SqFill** as a **postulate** blocks computation. If **SqFill** appears in a term:

... **SqFill** $(\mathbb{N} \to (\mathbb{N} \times \mathrm{Bool})$ ...

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Everything else around it evaluates, but it doesn't.

Like x in $42 + x$, can never return a value.

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Proof by induction on the type: reduces to base cases, and computes away.

Live Demo: Cubical-UIP in Agda

Cubical Agda: SqFill as a stuck axiom:

```
-- postulated, never reduces
postulate
  prim^sqFill : ∀ (A : Type) → SqFill A

-- doesn't hold automatically!
test-computes : sqFill-block refl refl ≡ refl
test-computes = {! refl !} -- LHS does not reduce
```

Cubical-UIP: SqFill that computes:

```
-- dispatches by type, always reduces
primitive
  prim^sqFill : ∀ (A : Type) → SqFill A

-- computes!
test-computes : sqFill-block refl refl ≡ refl
test-computes = refl
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 Live Demo with **Cubical-UIP**!

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Base cases: types where equality is obviously unique, a proof is directly given.

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Proof by induction on the type: the type checker assembles the proof automatically.

Summary: SqFill for each type former

Full Agda proofs with beautiful diagrams [TND25] available.

Type former		**Difficulty**
$\Pi(a : A).B\ a$ (functions)[1]	:	Trivial: pointwise, no path manipulations needed[2]
$\Sigma(a : A).B\ a$ (dependent pairs)[3]	:	**Involved**: complex path manipulations[4]
$A \uplus B$ (coproducts)	:	Standard: encode, manipulate, decode
$\mathbb{N}$ (natural numbers)	:	Standard: encode, manipulate, decode
$a =_A b$ (path types)	:	Simple: a single path composition[5]
$\mathcal{U}$ (the universe)	:	**Open question**: see next slide

[1] Non-dependent ($A \to B$) is a special case: also trivial.

[2] No Kan operations (hcomp/transport) required.

[3] Non-dependent ($A \times B$) is a special case that's trivial.

[4] Requires transport-fill-align: transport along a line of types, fill a box, then align the result via hcomp.

[5] A single hcomp suffices.

Open question: what about the universe? 🪐

So far: SqFill computes for **concrete** type formers: Π, Σ, $A \uplus B$, $\mathbb{N}$, $a =_A b$.

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Two approaches, both open:

- **Approach A**: treat $\mathcal{U}$ as an inductive type with one constructor per type former — inspect it the same way we inspect $A \times B$, $A \to B$, etc.[1]
- **Approach B** (speculative — merely an idea at this stage): SqFill becomes a new type former itself, with the so-called ***Weld*** types[2].

[1] Formally: an inductive-recursive (IR) universe with a typecase operator, in the style of Dybjer [Dyb00] / Dybjer-Setzer [DS99] / XTT [SAG22]. This makes the type theory anti-classical [CD18, Hur10], invalidating excluded middle — but univalence is already disabled.

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Ask us after the talk if you want to know more!

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Conclusion: Cubical Agda with funext, quotients, and UIP — and it computes

TL;DR: Want all of the following?

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You are in luck! We implemented these Agda variants:

✅ `--cubical=no-glue`: removes the one feature (*Glue*) incompatible with UIP

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Work in progress: 🚧

- Universe case: IR universe via typecases
- Path types and generic inductive types
- Canonicity and Normalisation
- Evaluate advantage in projects that needed Computational UIP [CNT26, HC21]

Thank you!

Questions?

https://github.com/yeejian-tan/agda/tree/cubical-uip

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