

Efficient Coinductives through State-Machine Corecursors

Optimising the terminal F-coalgebra in Set
for computational behaviour in Lean4

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Polynomials (background)

- A head H ,
- child families c_h in $h : H$.
- Morally, a collection of constructors H , and data at each constructor c_h .
- For now we will not consider “recursive” (inductive) data structures, rather I will have this be a variable we take the fix point in.
- Examples:
 - ▶ natural numbers `NatF(X) := 1 + X,`
 - ▶ lists `ListF(A, X) := 1 + A * X,`
 - ▶ streams `StreamF(A, X) := A * X.`

$$(h : H) \times c_h \rightarrow \alpha \equiv \sum_{h:H} \alpha^{c_h}$$

See (nLab authors, 2026) and (Neel Krishnaswami, 2026)

Coinductives (background)



- Unbounded tree of data.
- Greatest cofixpoint of a polynomial.
- Morally, the process of putting the word “lazy” in front of a functor,
 - ▶ on lists it sends them to lazy lists.
- Have a corecursion principle rather than an recursion principle,
 - ▶ instead of `rec` : $(f\ a \rightarrow a) \rightarrow \text{fix } f \rightarrow a$,
 - ▶ we have `corec` : $(a \rightarrow f\ a) \rightarrow a \rightarrow \text{cofix } f$.
- On our examples and their correspondencens,
 - ▶ `cofix NatF`, natural numbers union infinity,
 - ▶ `cofix ListF(A)`, lists of `A`s with arbitrary length union streams of `A`,
 - ▶ `cofix StreamF(A)`, infinite streams of `A`s.

See (Avigad et al., 2019)

Perfomance of coinductives (core)



- Previous work has demonstrated implementation of coinductives.
- Computational behaviour was not a concern.

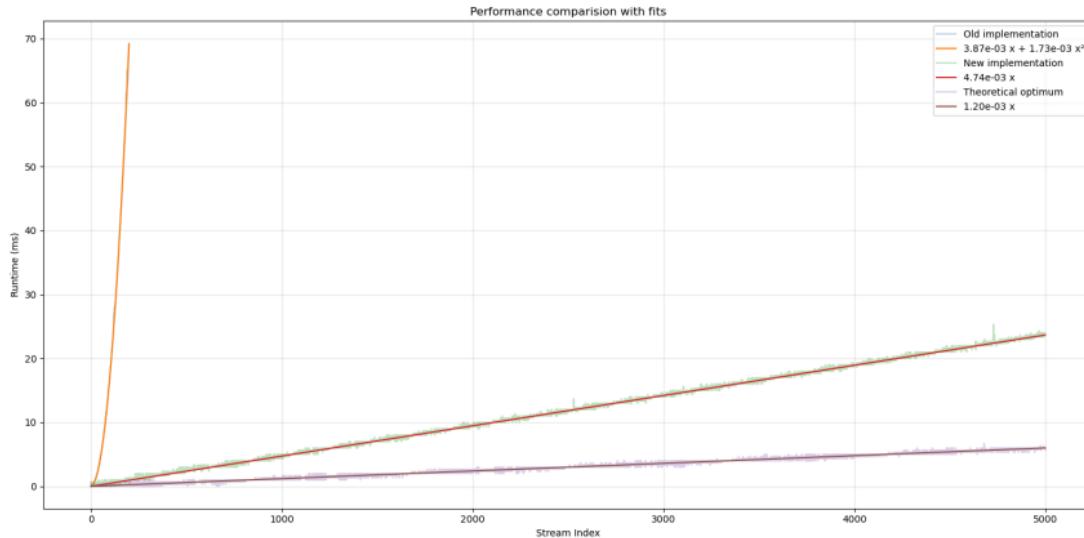


Figure 1: Perfomance of the old, new, and a perfect implementation

ABI Type (extention)



- Given $\alpha : \text{Type}_{\mathcal{U}}$, $\beta : \text{Type}_{\mathcal{V}}$ and $\text{eq} : \alpha \simeq \beta$.
- Univalence gives uniqueness.
- Adds a form of “weak-univalence”.
- Allows for a zero cost universe transliteration.
- Symetric form of Shrink.

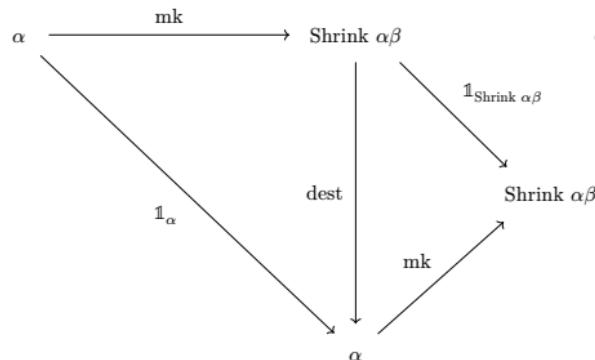


Figure 2: Operations on Shrink

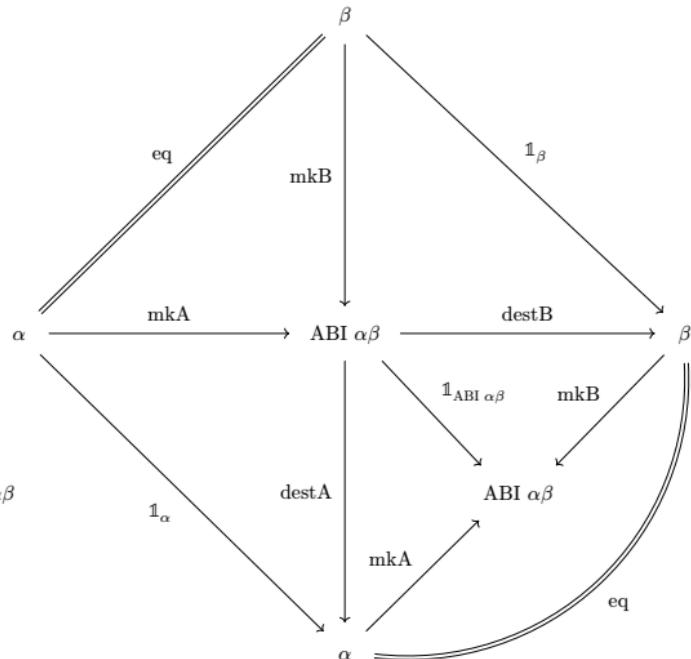


Figure 3: Operations on ABI

Interaction Trees (extention)



- Free monad with non-termination as an effect.

```
1 coinductive ITree
2   (E : Type u → Type u) (R : Type v) :=
3   | tau : ITree E R → ITree E R
4   | ret : R → ITree E R
5   | vis {A : Type u} (e : E A) (k : A → ITree E R)
```

Lean

- ITerm E forms a monad,
 - ▶ With a method trigger : $EV \rightarrow \text{ITree } E V$,
 - ▶ and iter : $(A \rightarrow \text{ITree } E(A + B)) \rightarrow A \rightarrow \text{ITree } E B$.
- And an equivalence relation $A \approx B$,
 - ▶ satisfying $A \approx B \leftrightarrow \text{tau } A \approx B$.

Project statistics

```
> nix-shell -p cloc --run "cloc . --exclude-dir=.lake"
 100 text files.
 92 unique files.
 14 files ignored.
```

github.com/AlDanial/cloc v 2.06 T=0.08 s (1110.8 files/s, 124656.0 lines/s)

Language	files	blank	comment	code
Lean	59	1229	252	6621
Typst	20	332	122	1099
SVG	1	0	0	171
JSON	3	0	0	125
TeX	1	4	0	76
YAML	3	8	7	69
Markdown	2	27	0	68
Python	2	22	18	57
Nix	1	2	0	15
SUM:	92	1624	399	8301

(excluding mathlib PRs)

Bibliography

- Avigad, J., Carneiro, M., & Hudon, S. (2019). Data Types as Quotients of Polynomial Functors. In J. Harrison, J. O'Leary, & A. Tolmach (Eds.), *10th International Conference on Interactive Theorem Proving (ITP 2019): Vol. 141. 10th International Conference on Interactive Theorem Proving (ITP 2019)*. <https://doi.org/10.4230/LIPIcs.ITP.2019.6>
- Neel Krishnaswami. (2026, February). *Algebraic Techniques for Programming* 25-26.
- nLab authors. (2026, January). *polynomial functor*.
- Yang, Z., & Wu, N. (2022). Fantastic Morphisms and Where to Find Them. In E. Komendantskaya (Ed.), *Mathematics of Program Construction: Mathematics of Program Construction*.

Further work

Futumorphic productivity (extention)

- A futomorphism is a morphism $(c \rightarrow f (\text{Free } f c)) \rightarrow c \rightarrow \text{cofix } f$.
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See (Yang & Wu, 2022)

CTree (extention)

CTree