Bounded Sort Polymorphism with Elimination Constraints

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A Bit of a Dry Start, Right?

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Elder's Wisdom

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- polymorphism,
- etc.

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That was before multi-sorted type theories *join the battle*.

Multi-Sorted What?

Setting:

$$t, u \quad ::= \quad x \mid t\ u \mid \lambda x.\ t \mid \Pi(x : t).\ u \mid \texttt{Type}_\ell$$

+ inductives and records (and their introduction/elimination).

where

- x is a variable
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in $\mathbb{G}$, we have

- a distinguished sort $\mathtt{Type}$ s.t. $\vdash \mathcal{U}_\ell^s : \mathcal{U}_{\ell+1}^{\mathtt{Type}}$,
- predicative sorts $\mathbb{G}_P$,
- impredicative sorts $\mathbb{G}_I$.

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By s_I *impredicative*, we mean:

$$\frac{\Gamma \vdash A : \mathcal{U}_\ell^s \qquad \Gamma, x : A \vdash B : \mathcal{U}_{\ell'}^{s_I}}{\Gamma \vdash \Pi(x : A).\ B : \mathcal{U}_{\ell'}^{s_I}}$$

Grounded in Reality

Ground sorts:

- Agda: $\mathbb{G}_P = \{\texttt{Set}, \texttt{Prop}\}$, $\mathbb{G}_I = \emptyset$,
- Lean: $\mathbb{G}_P = \{\texttt{Type}\}$, $\mathbb{G}_I = \{\texttt{Prop}\}$,
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`Prop`/`SProp`	(irrelevant) proofs

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Induce a small restriction: cannot create computational content from proofs.

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In practice,[1] also leads to the *dreaded* duplication:

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Inductive sumbool (A B : Prop) : Type :=
| left : A → sumbool A B
| right : B → sumbool A B.

Inductive or (A B : Prop) : Prop :=
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Not All Heroes Wear Capes

Poiret et al. saved us from this world of suffering with SortPoly:

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Inductive sum@{sl sr s ; ul ur}
  (A : 𝒰@{sl ; ul}) (B : 𝒰@{sr ; ur}) : 𝒰@{s ; max(ul, ur)} :=
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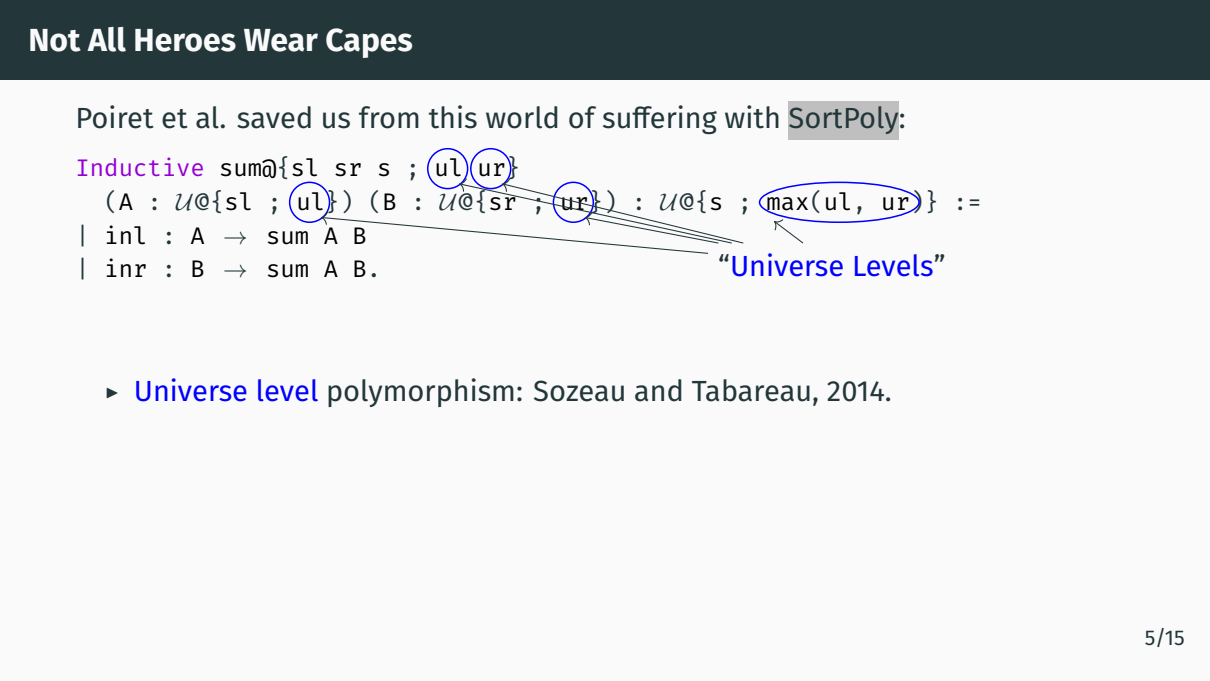

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But this is not enough to avoid duplication!

A Non-Improved Situation

With unbounded sort polymorphism: cannot define *e.g.*, a generic eliminator:

```
Definition sum_elim@{sl sr s s'}
  {A : 𝒰@{sl}} {B : 𝒰@{sr}} {C : sum@{sl sr s} A B → 𝒰@{s'}}
  (u : sum@{sl sr s} A B) (f : forall (x : A), C (inl x))
  (g : forall (y : B), C (inr y)) : C u :=
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Still need to declare the different eliminators “by hand”.

Contributions

In SortPoly, no principal sort assignment for e.g.:

```
Fixpoint map {A B} (f: A → B) (l: list A): list B :=
  match l with [] ⇒ [] | a :: t ⇒ f a :: map f t end.
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We introduce a bounded sort-polymorphic type system such that it:

- allows writing the most generic terms (w.r.t. sorts),
- allows infering the principal sort assignment,
- has relative consistency (w.r.t. SortPoly),
- has the *same* logical power as SortPoly.

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Our proposal: interactions between sorts using *elimination constraints*.

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Naturally models existing systems:

- Agda: `Set` $\rightsquigarrow$ `Set`, `Set` $\rightsquigarrow$ `Prop`, `Prop` $\rightsquigarrow$ `Prop`,
- Lean: `Type` $\rightsquigarrow$ `Type`, `Type` $\rightsquigarrow$ `Prop`, `Prop` $\rightsquigarrow$ `Prop`,
- Rocq: reflexive and transitive closure of `Type` $\rightsquigarrow$ `Prop`, `Prop` $\rightsquigarrow$ `SProp`.

I Plead Guilty

Elimination constraints are not so innocent:

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Lemma guilty@{s | SProp ⇝ s} : forall {A : 𝒰@{s}} (x y : A), x = y.
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$\Longrightarrow$ for the typechecking to be right, have to inherit conversion rules!

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Theorem

Assuming SortPoly is consistent, then there does not exist a well-typed closed term $t : \bot^s$ in SortPoly$\tilde{\gamma}^{\rightarrow}$ for s a consistent sort.

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Let's talk about the required conditions.

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  Works, but not alone: need conditions.

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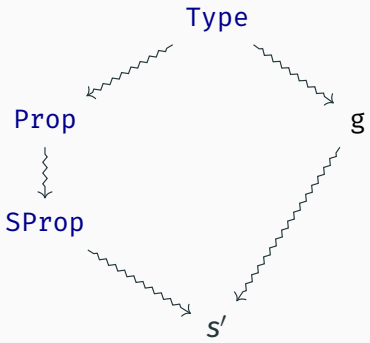
Introducing Domination (ಠ_ಠ)

Second attempt: take minimal ground g s.t. $g \rightsquigarrow s'$.

Does not always exist!



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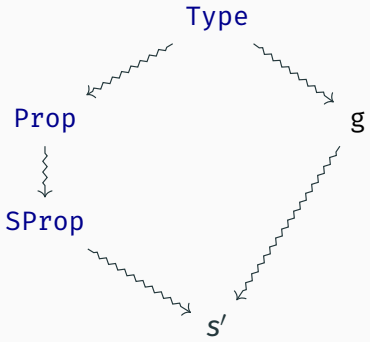

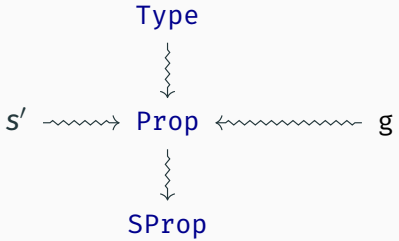

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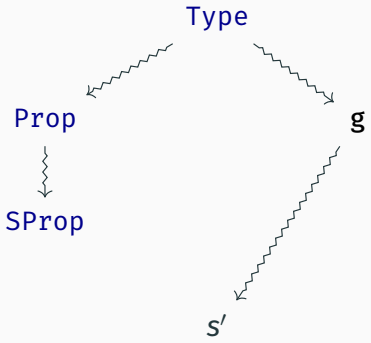

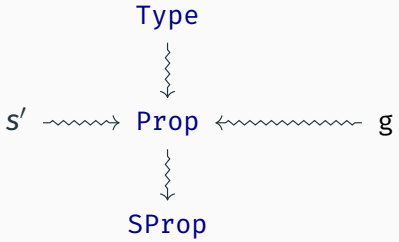

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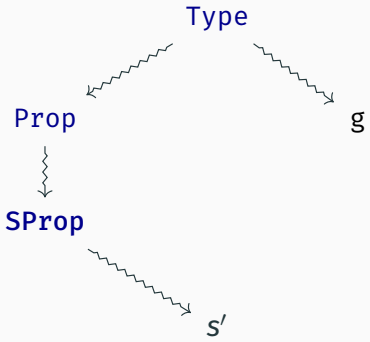

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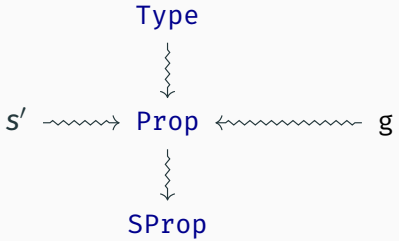

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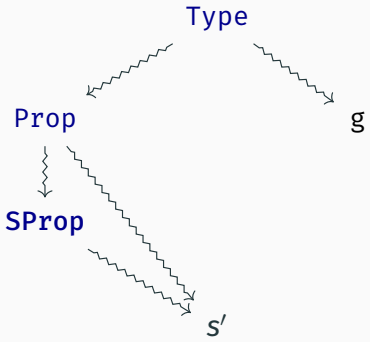

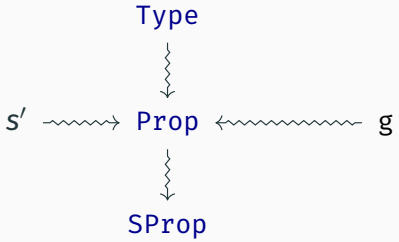

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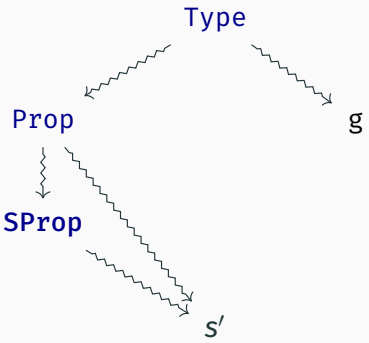
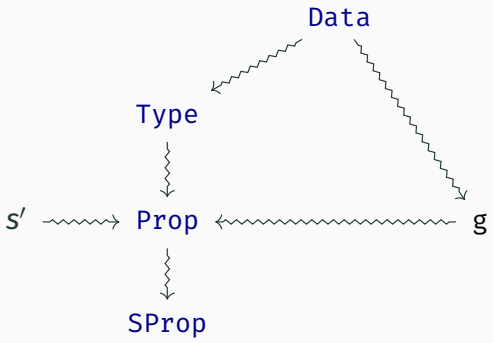
What about strays?
have an initial sort `Data`





Let's End This Damn Proof

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For a closed $t : \bot^s$, instantiate away sort variables.

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Under these conditions: instantiate by taking dominant ground sort (or initial sort if there are no dominants).

Rocq'n'Rolling

Implementation of elimination constraints in Rocq:

- ad-hoc checks for dominant sorts (amortized constant complexity),
- (current implementation restriction) manual prohibition of `SProp` $\rightsquigarrow$ `s`,
- elaboration to get principal sort assignment.

Some performance regressions ($\approx 4\%$) in the monomorphic case:

- eliminability check through a graph,
- bigger structures at elaboration.

Check out the RFC!

This is Goodbye (For Now)

We have extended the type system of SortPoly so that our extension:

- has relative consistency w.r.t SortPoly,
- has the same logical power as SortPoly,
- has a principal sort assignment,
- has an elaboration procedure yielding the principal sort.

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Any question(s)?