Isabelle/DOF
A Framework for Proving Ontology-Relations and Runtime Testing
Ontology Instances

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GT Deduction 17.2.2022

Overview

- Why (Document) Ontologies
- Ontologies and Formal Theories
- DOF Design
- Isabelle/DOF Implementation
- Some Application Scenarios

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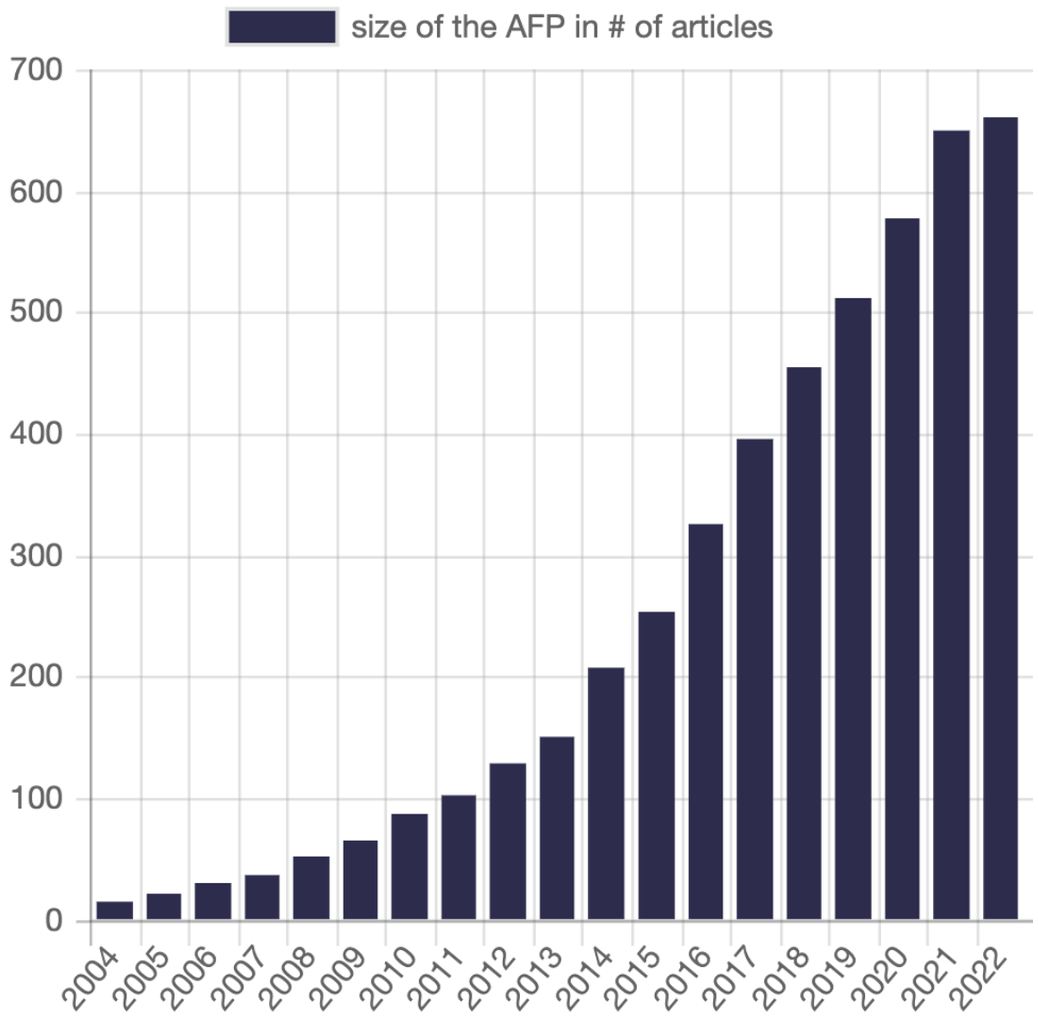
http/10.5281/zenodo.3370483

Why Ontologies



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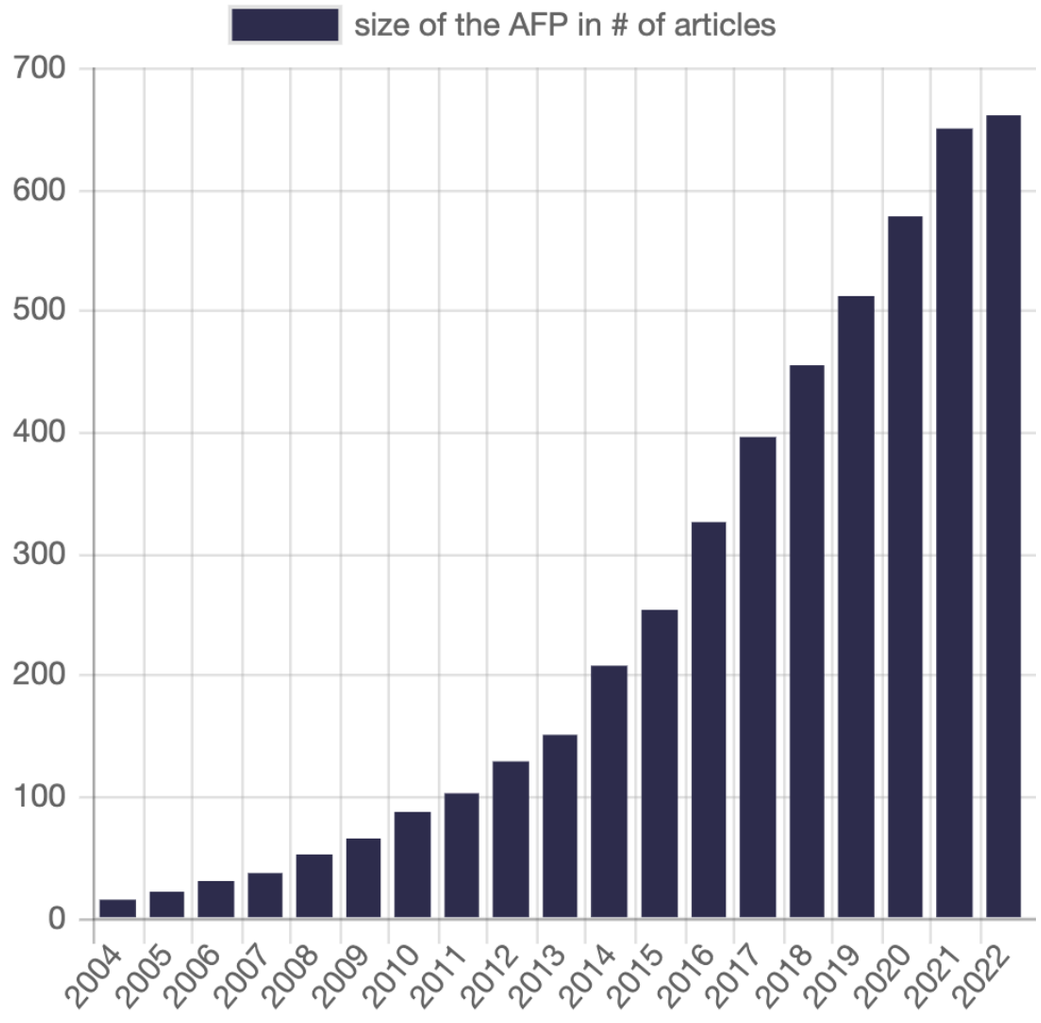

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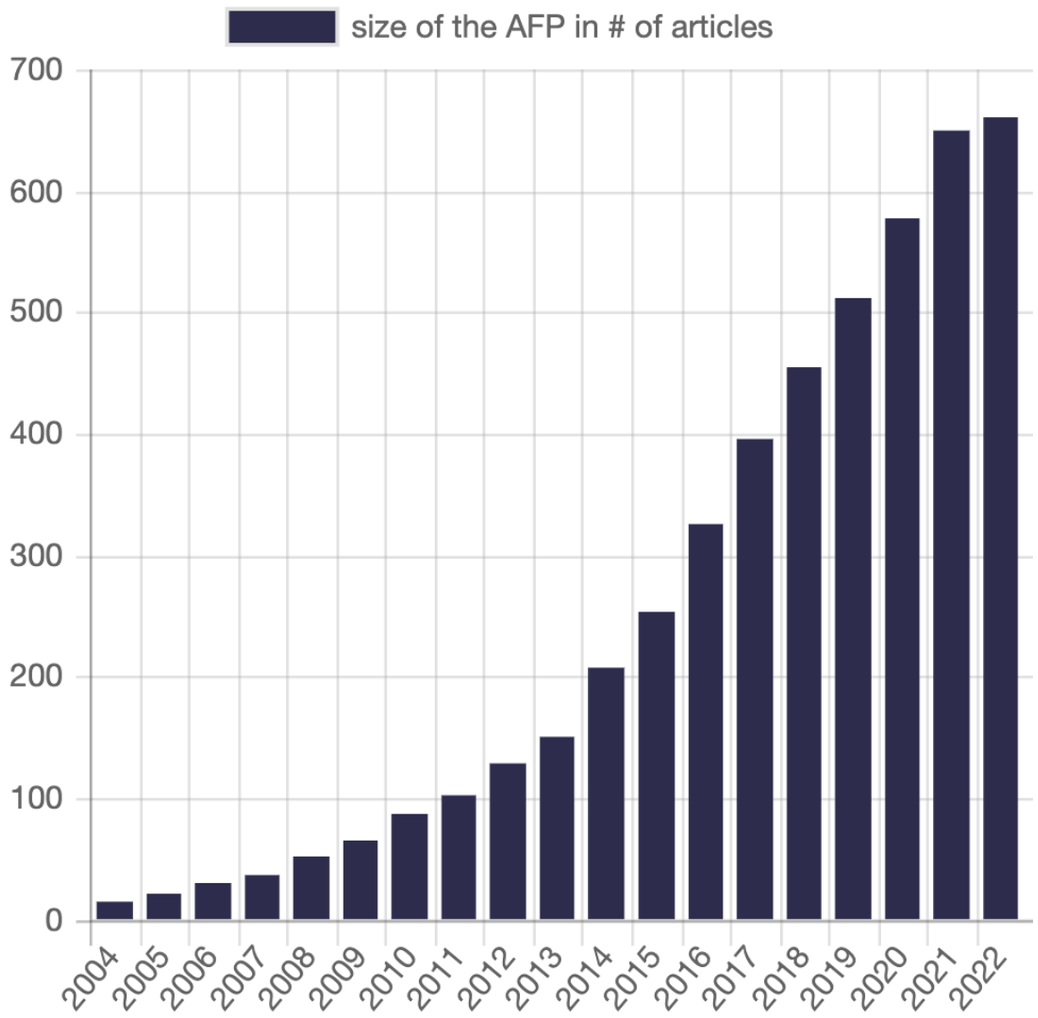

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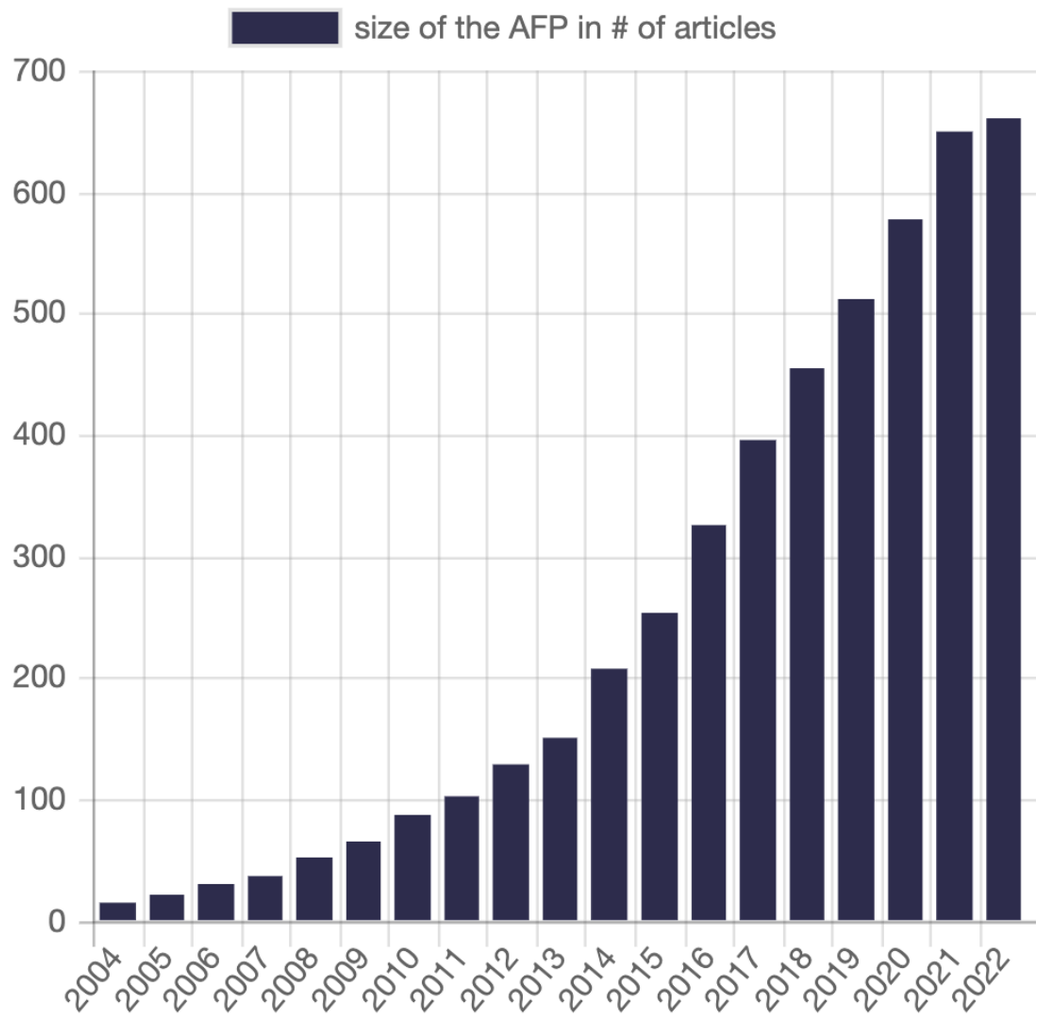

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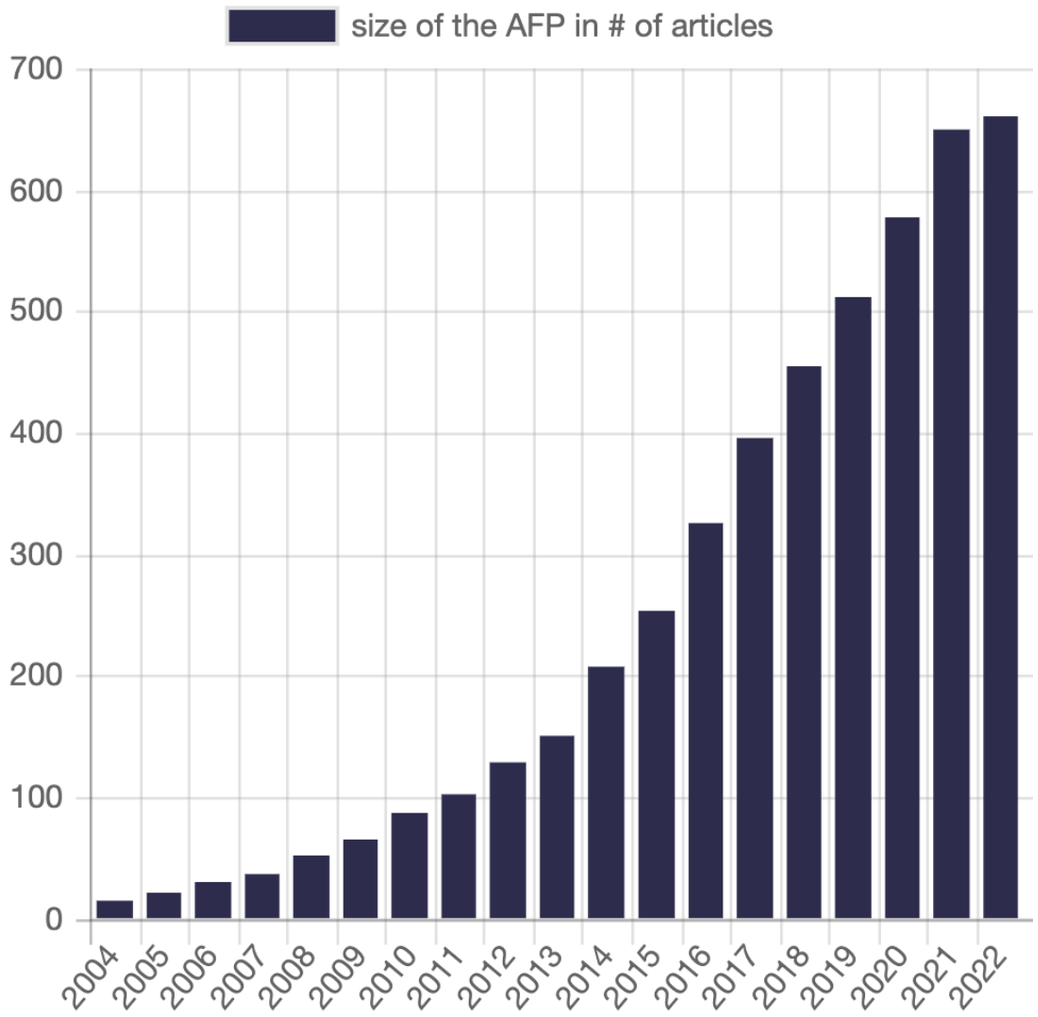

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  - advanced “semantic” search,
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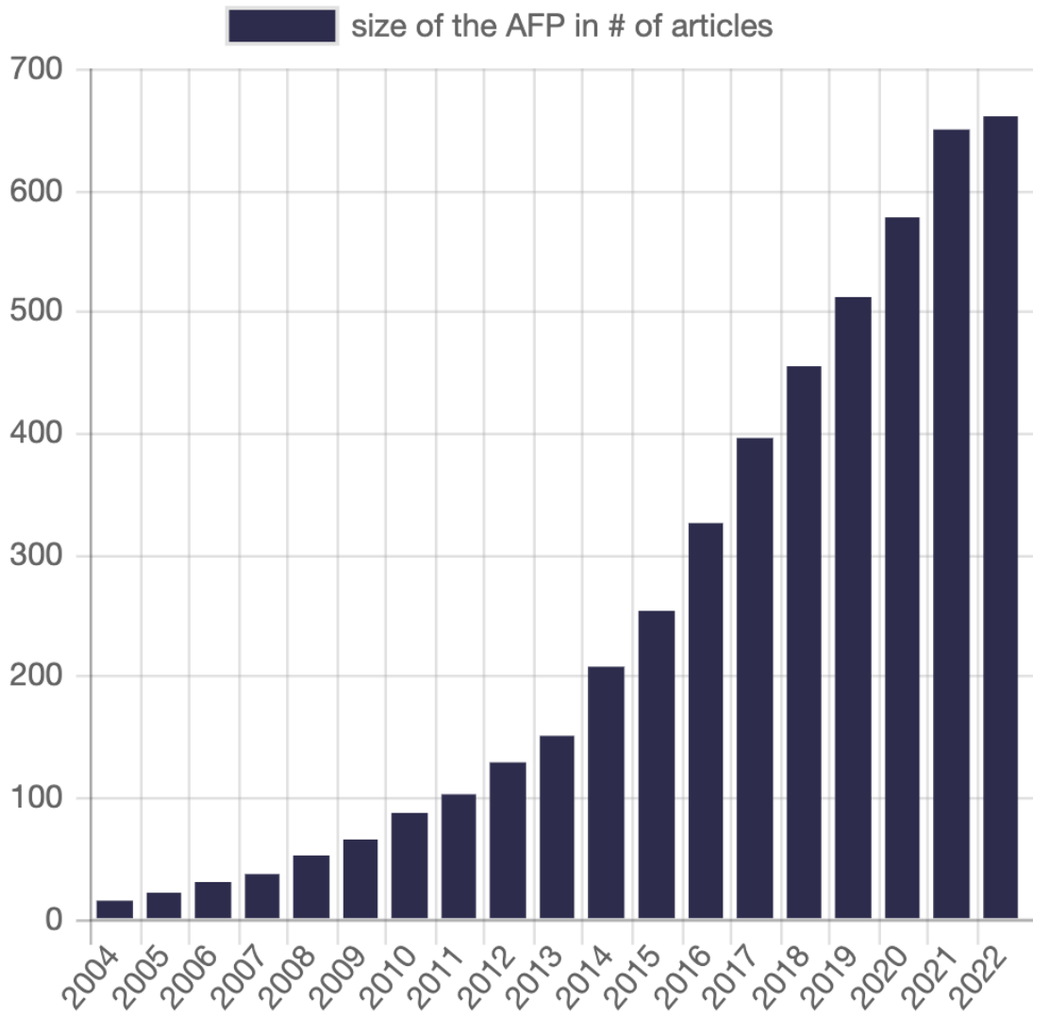

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- The language in which such meta-information can be specified
  is called a *document ontology* (or *vocabulary*)

Linking the Formal and the Informal - Existing Approaches -

- Code Antiquotations as in LISP, MetaML, SML, …

```
-| val z = <f 4 5>;
val z = <%f 4 5> : <int>

-| let fun f x y = not x andalso y in run z end;
val it = 8 : int
```

- Document pragmas as in JavaDoc, Doxygen, et al

```
public class AddNum {
  /**
   * This method is used to add two integers. This is
   * a the simplest form of a class method, just to
   * show the usage of various javadoc Tags.
   * @param numA This is the first paramter to addNum method
   * @param numB  This is the second parameter to addNum method
   * @return int This returns sum of numA and numB.
   */
   public int addNum(int numA, int numB) {
     return numA + numB;
   }
```

- Compilation process allows for document generation and some consistency checks

  $\Longrightarrow$ batch mode consistency only.

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fun ltx_of_term _ _ (Const (@{const_name ‹Cons›},
                            @{typ "char ⇒ char list ⇒ char list"}) $ t1 $ t2)
        = HOLogic.dest_string (Const (@{const_name ‹Cons›},
                                      @{typ "char ⇒ char list ⇒ char list"}) $ t1 $  t2)
  | ltx_of_term _ _ (Const (@{const_name ‹Nil›}, _)) = ""
  | ltx_of_term _ _ (@{term "numeral :: _ ⇒ _"} $ t) = Int.toString(HOLogic.dest_numeral t)
  | ltx_of_term ctx encl ((Const (@{const_name ‹Cons›}, _) $ t1) $ t2) =
      let val inner = (case t2 of
                         Const (@{const_name ‹Nil›}, _) =>  (ltx_of_term ctx true t1)
                       | _ => ((ltx_of_term ctx false t1)^", " ^(ltx_of_term ctx false t2))
                      )
      in if encl then enclose "{" "}" inner else inner end
  | ltx_of_term _ _ (Const (@{const_name ‹None›}, _)) = ""
  | ltx_of_term ctxt _ (Const (@{const_name ‹Some›}, _)$t) = ltx_of_term ctxt true t
  | ltx_of_term ctxt _ t = ""^(Sledgehammer_Util.hackish_string_of_term ctxt t)
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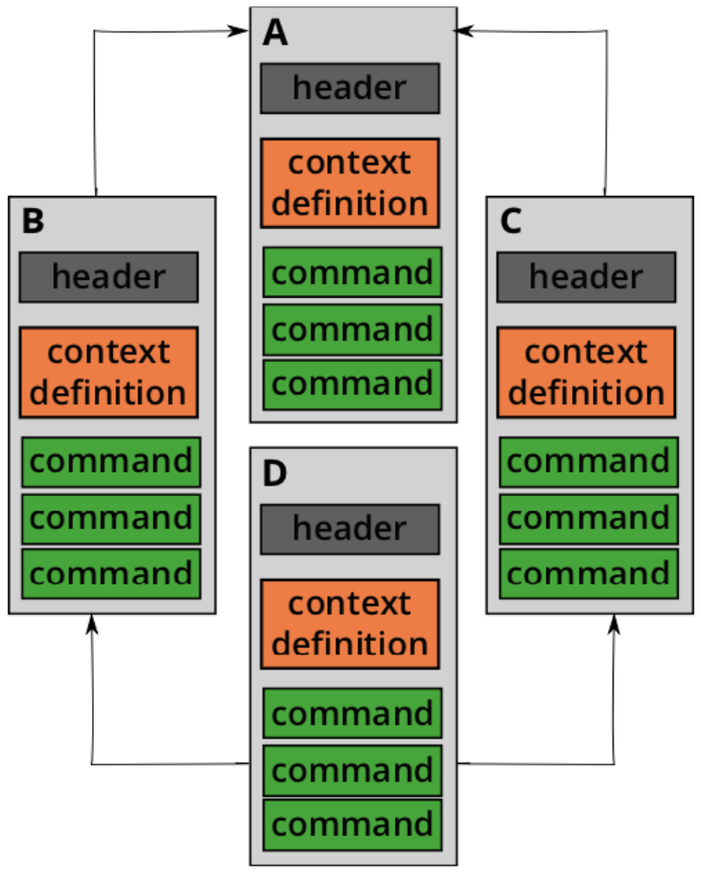

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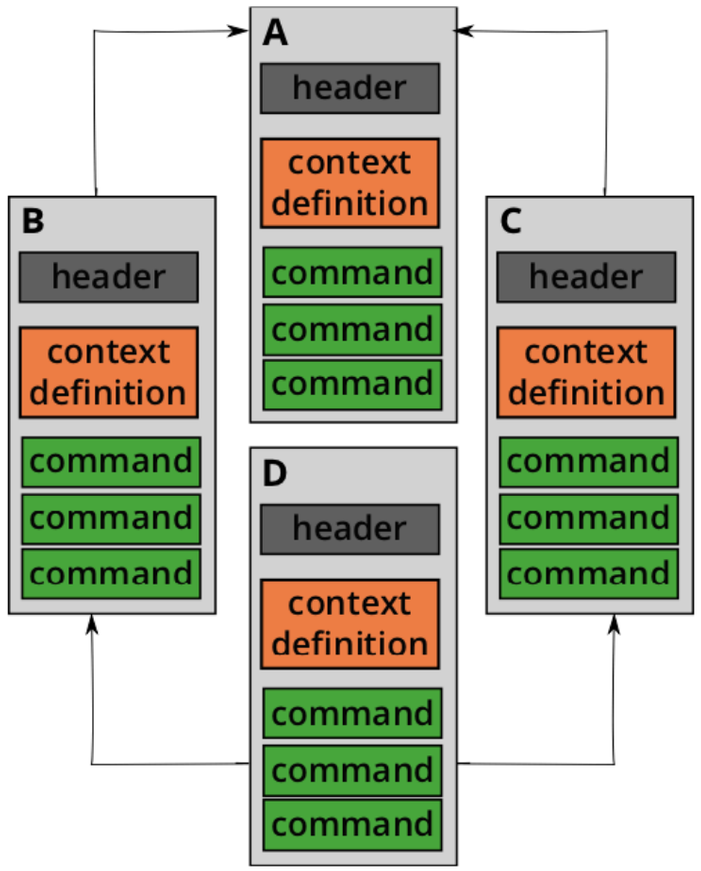

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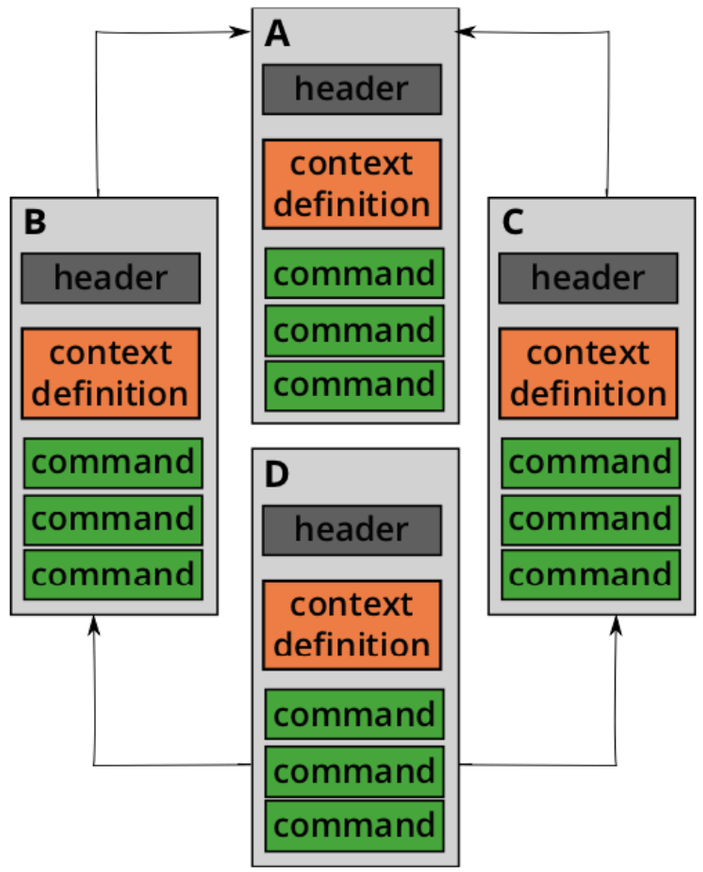

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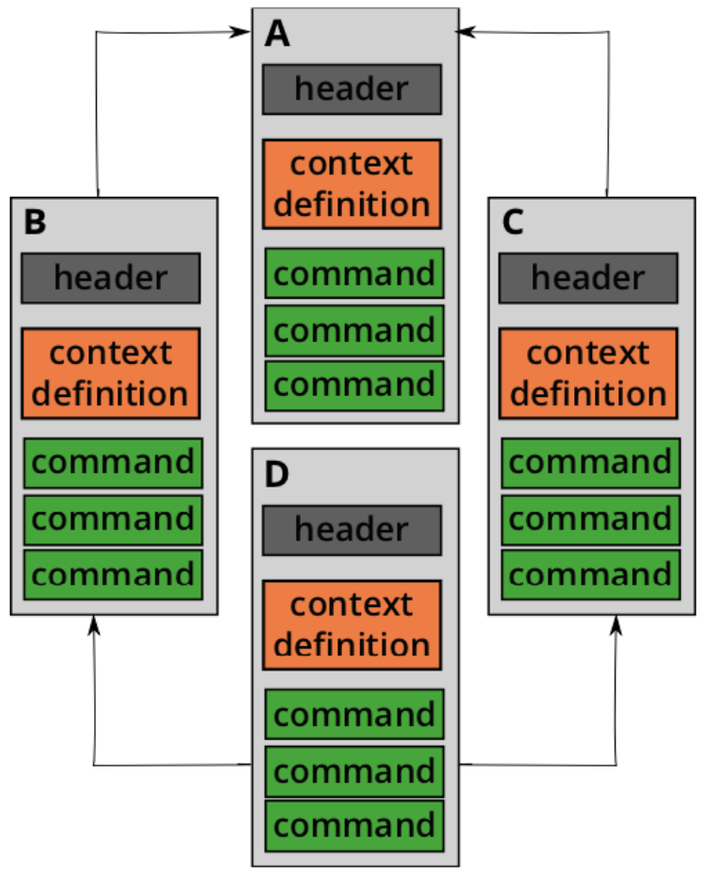

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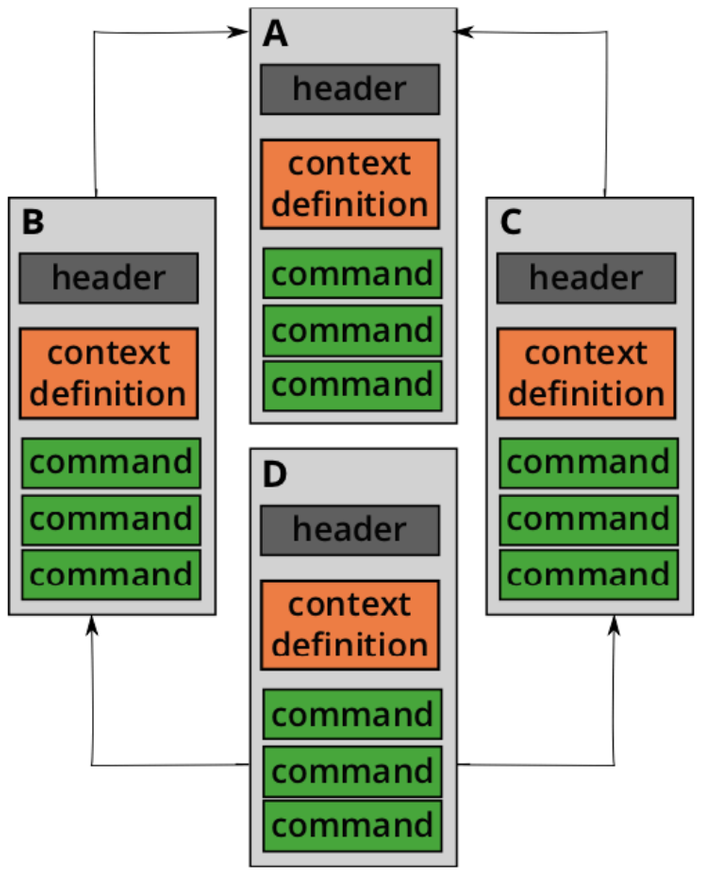

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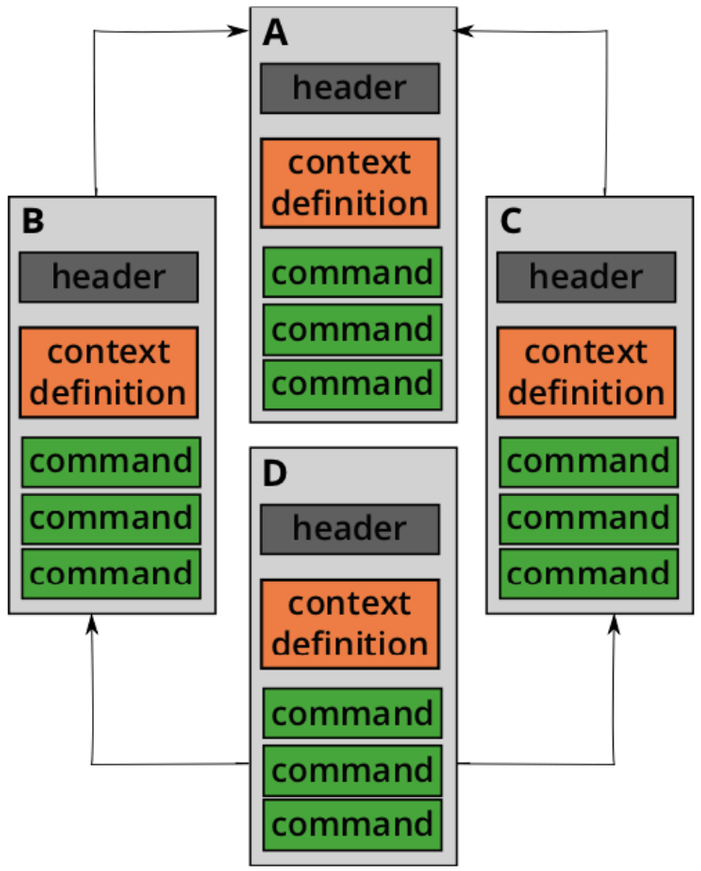

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- *pervasive continuous build/check of Isabelle/PIDE supports anti-quotations.*

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- class declarations induce a HOL-type; this allows to establish “ontological links”

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  The Mechanism to d*efine* Ontologies

- Features:
  - classes (for the “concepts”)
  - classes may have attributes with HOL type
  - class declarations can be interleaved with arbitrary HOL declarations
  - attributes of class-instances are mutable; (default) values can be denoted by HOL-terms

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doc_class title  = short_title :: "string option" <= "None"
doc_class author = email      :: "string" <= ''''''

datatype classification = SIL0 | SIL1 | SIL2 | SIL3 | SIL4

doc_class abstract =
    keywordlist :: "string list"      <= []
    safety_level :: "classification"  <= "SIL3"
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- class declarations induce a HOL-type; this allows to establish “ontological links”

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type_synonym notion = string

doc_class introduction = text_section +
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    uses :: "notion set"
doc_class claim = introduction +
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doc_class technical = text_section +
    formal_results  :: "thm list"
doc_class "definition" = technical +
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abstract*[abs, safety_level="SIL4", keywordlist = "[''controller'']"]⟨
  We present a formalization of a program which serves to control the
  level of water in a steam boiler.
⟩

section*[intro::introduction]⟨Introduction⟩
text⟨We present ...⟩

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text⟨
  The system comprises the following units
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  • a device to measure the quantity of water in the steam-boiler
  • ...
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$\forall\ \sigma \in \text{result}.\ \text{evidence}\ \sigma = \text{proof} \longleftrightarrow \text{property}\ \sigma \neq []$

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—> definition <lab>_inv :: ‘a result_scheme ⇒ bool”

where “ <lab>_inv σ ≡ evidence σ = proof ⟷ property σ ≠ []

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  - *may use DOF-generated term-antiquotations like @{result ''<some result instance>"} or @{introduction ''intro"} or @{instance-of ''result"}, etc.*

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$\forall\ \sigma \in \text{conclusion}.\ \forall\ x \in \text{Domain}(\text{establish}\ \sigma).$
$\exists\ y \in \text{Range}(\text{establish}\ \sigma).\ (x, y) \in \text{establish}\ \sigma$

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~~∀ σ ∈ conclusion. ∀ x ∈ Domain(establish σ).~~
~~∃ y ∈ Range(establish σ). (x, y) ∈ establish σ~~

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∀ σ ∈ conclusion. ∀ y ∈ @{instance_of ‘’claim”}.
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- We can relate ontologies and ontology instances by formal proof (‘’ontology alignment, ontology mapping”)

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Isabelle code

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definition sum
  where "sum S = (fold (+) S 0)"

datatype Hardware_Type =
  Motherboard |
  Expansion_Card |
  Storage_Device |
  Fixed_Media |
  Removable_Media |
  Input_Device |
  Output_Device

onto_class Resource =
  name :: string

onto_class Electronic = Resource +
  provider :: string
  manufacturer :: string

onto_class Component = Electronic +
  mass :: int
  dimensions :: "int list"

onto_class Simulation_Model = Electronic +
  type :: string

onto_class Informatic = Resource +
  description :: string

onto_class Hardware = Informatic +
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  invariant c1 :: "mass σ = sum(map Component.mass (composed_of σ))"
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  provider :: string
  mass :: int

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  version :: int

onto_class Electronic_Component = Product +
  dimensions :: "int set"

onto_class Computer_Hardware = Product +
  type :: Hardware_Type
  composed_of :: "Product list"
  invariant c2 :: "Product.mass σ = sum(map Product.mass (composed_of σ))"
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  dimensions :: "int list"

onto_class Simulation_Model = Electronic +
  type :: string

onto_class Informatic = Resource +
  description :: string

onto_class Hardware = Informatic +
  type :: Hardware_Type
  mass :: int
  composed_of :: "Component list"
  invariant c1 :: "mass σ = sum(map Component.mass (composed_of σ))"
```

Isabelle code

```
onto_class Item =
  name :: string

onto_class Product = Item +
  serial_number :: int
  provider :: string
  mass :: int

onto_class Computer_Software = Item +
  version :: int

onto_class Electronic_Component = Product +
  dimensions :: "int set"

onto_class Computer_Hardware = Product +
  type :: Hardware_Type
  composed_of :: "Product list"
  invariant c2 :: "Product.mass σ = sum(map Product.mass (composed_of σ))"
```

Consequences: Example Proof of an Ontology Mapping

- A “‘Generic’ Reference Ontology” vs. a “‘local’ Ontology”

Isabelle code

```
definition sum
  where "sum S = (fold (+) S 0)"

datatype Hardware_Type =
  Motherboard |
  Expansion_Card |
  Storage_Device |
  Fixed_Media |
  Removable_Media |
  Input_Device |
  Output_Device

onto_class Resource =
  name :: string

onto_class Electronic = Resource +
  provider :: string
  manufacturer :: string

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```
definition Computer_Hardware_to_Hardware_morphism ::
            "'a Computer_Hardware_scheme ⇒ Hardware"
            ("_ ⟨Hardware⟩ComputerHardware" [1000]999)
          where "σ ⟨Hardware⟩ComputerHardware =
                (⦇ Resource.tag_attribute = 2::int ,
                   Resource.name = name σ ,
                   Informatic.description = ''no description'',
                   Hardware.type = Computer_Hardware.type σ ,
                   Hardware.mass = mass σ ,
                   Hardware.composed_of =
                                map Product_to_Component_morphism
                                    (Computer_Hardware.composed_of σ) ⦈"
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Isabelle code

```
lemma inv_c2_preserved :
  "c2_inv σ ⟹ c1_inv (σ ⟨Hardware⟩_ComputerHardware)"
  unfolding c1_inv_def c2_inv_def
            Computer_Hardware_to_Hardware_morphism_def
            Product_to_Component_morphism_def
  using comp_def by (auto)

lemma Computer_Hardware_to_Hardware_morphism_total :
 "Computer_Hardware_to_Hardware_morphism ' ({X::Computer_Hardware. c2_inv X})
    ⊆ ({X::Hardware. c1_inv X})"
  using inv_c2_preserved by auto
```

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```
definition  typ_anno :: “string ⇒ typ” where  “typ_anno S ≡ undefined”

datatype “typ”   =  is_Ty : Ty name “typ list”
                  |  is-Tv : Tv variable sort
datatype “term” = is_Ct : Ct name “typ”
                  |  is_Fv: Fv variable “typ”
                  | is_Bv: Bv nat
                  | is_Abs : Abs “typ” “term”
                  | is_App : App “term” “term” {infixl “$” 100)
```

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