The Abstract Syntax as Ontology

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3. Semantic Web
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What is ontology?

Ontology is the philosophical study of the nature of being, existence or reality in general, as well as of the basic **categories** *of being and their* **relations**. *Traditionally listed as a part of the major branch of philosophy known as metaphysics, ontology deals with questions concerning what* **entities** *exist or can be said to exist, and how such entities can be grouped, related within a* **hierarchy**, *and subdivided according to similarities and differences.*

Wikipedia

Ontologies in C++

The Object Oriented Modeling is building an Ontologies for some concrete domain.

C++

class *Shape* { . . . }
class *Triangle* : *Shape* { . . . }
class *Rectangle* : *Shape* { . . . }
class *Square* : *Rectangle* { . . . }

The inheritance graph is also called Taxonomy

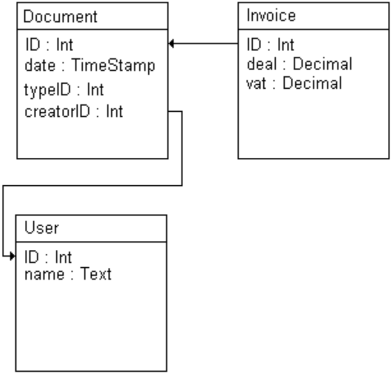
Ontological Relations

Classes have properties, members, fields they define relations between entities in the ontology.

C++

class *Rectangle* : *Shape* { *Point topleft*, *bottomright*; }
class *Point* { int x,y; }

The database schema is an ontology defined using relational algebra.



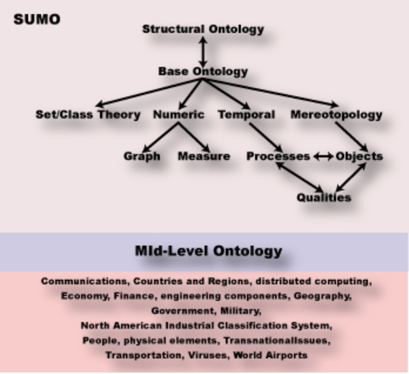
Object models could be defined in a family of languages RDF, RDFS, OWL Lite, OWL Full

```
<shapes:Rectangle rdf:about="#R123">
    <shapes:topleft>
        <shapes:Point>
            <shapes:x>10 </shapes:x>
            <shapes:y>10 </shapes:y>
        </shapes:Point>
    </shapes:topleft>
    <shapes:bottomright>
        <shapes:Point>
            <shapes:x>100 </shapes:x>
            <shapes:y>100 </shapes:y>
        </shapes:Point>
    </shapes:bottomright>
</shapes:Rectangle>
```

OWL allows light inference also: inverse properties, transitivity etc.

Suggested Upper Merged Ontology (SUMO)

- The biggest open source ontology - 20000 concepts and 70000 axioms
- Mapping to WordNet
- Language generation templates for Hindi, Chinese, Italian, German, Czech and English
- Partial export to OWL



Ontologies in Type Theory

Dependently Types Languages - GF, Agda, Epigram, Coq . . .

$$
\begin{aligned}
&\textbf{cat}\ \ \mathit{Shape};\\
&\phantom{\textbf{cat}}\ \ \mathit{Triangle};\\
&\phantom{\textbf{cat}}\ \ \mathit{Rectangle};\\
&\phantom{\textbf{cat}}\ \ \mathit{Point};
\end{aligned}
$$

$$
\begin{aligned}
&\textbf{fun}\ \ \mathit{triangle} : \mathit{Point} \longrightarrow \mathit{Point} \longrightarrow \mathit{Point} \longrightarrow \mathit{Triangle};\\
&\phantom{\textbf{fun}}\ \ \mathit{rectangle} : \mathit{Point} \longrightarrow \mathit{Point} \longrightarrow \mathit{Rectangle};\\
&\\
&\phantom{\textbf{fun}}\ \ \mathit{shapeTri} : \mathit{Triangle} \longrightarrow \mathit{Shape};\\
&\phantom{\textbf{fun}}\ \ \mathit{shapeRect} : \mathit{Rectangle} \longrightarrow \mathit{Shape};
\end{aligned}
$$

Why Ontology Matters in Linguistics?

- WordNet
  - every synset is a semantic concept
  - hierarchy of hypernyms and hyponyms
  - other relations - meronym/holonym
- VerbNet
  - primary valency dictionary
  - ...but also sortal restrictions
- FrameNet
  - knowledge about situations

Ontology vs Knowledge Base

Ontology vs Knowledge Base

- The ontology is the schema - definition of classes and properties
- The knowledge base is a set of instances, related by properties

In Grammatical Framework:

- Abstract Syntax $\equiv$ Ontology
- Expressions $\equiv$ Knowledge Base

Simple Types

The simple types are well known from every programming language

Types in Syntax

cat $NP, VP, S;$

fun $everyone\_NP : NP;$
$someone\_NP : NP;$

Types in Semantics

cat $Human, Company;$

fun $john\_H : Human;$
$google\_H : Company;$

Note: In GF there is not firm separation between syntax and semantics

Dependent Types

The dependent types are types indexed by some value. The dependency could be used to enforce semantic conditions.

Example:

Simply Typed

$$\textbf{cat}\ \mathit{Array};$$

$$\textbf{fun}\ \mathit{plus} : \mathit{Array} \longrightarrow \mathit{Array} \longrightarrow \mathit{Array}$$

Dependently Typed

$$\textbf{cat}\ \mathit{Array}\ \mathit{Int};$$

$$\textbf{fun}\ \mathit{plus} : (k : \mathit{Int}) \longrightarrow \mathit{Array}\ k \longrightarrow \mathit{Array}\ k \longrightarrow \mathit{Array}\ k$$

Reasoning

Knowledge about the world could be encoded in the abstract syntax

Travels Map

$$\begin{aligned}
&\textbf{cat}\ City;\\
&\quad Route\ City\ City;\\
\\
&\textbf{fun}\ gothenburg_C : City\\
&\quad stockholm_C : City\\
&\quad london_C : City\\
\\
&\textbf{fun}\ got2stk_R : Route\ gothenburg_C\ stockholm_C\\
&\quad stk2lon_R : Route\ stockholm_C\ london_C
\end{aligned}$$

Reasoning

We need one more function to make transfers

Travels Map

$$\begin{aligned}\textbf{fun}\ \mathit{join} : (c_1, c_2, c_3 : \mathit{City}) \\ &\rightarrow \mathit{Route}\ c_1\ c_2 \\ &\rightarrow \mathit{Route}\ c_2\ c_3 \\ &\rightarrow \mathit{Route}\ c_1\ c_3\end{aligned}$$

Travels Map

$$\begin{aligned}&\mathit{join}\ \mathit{gothenburg\_C}\ \mathit{stockholm\_C}\ \mathit{london\_C}\ \mathit{got2stk\_R}\ \mathit{stk2lon\_R} \\ &\quad : \mathit{Route}\ \mathit{gothenburg\_C}\ \mathit{london\_C}\end{aligned}$$

Computation

Every route has a distance which could be computed

Distance

fun $\mathit{dist} : (c_1, c_2 : \mathit{City}) \to \mathit{Route}\ c_1\ c_2 \to \mathit{Int};$

def $\mathit{dist}\ c_1\ c_2\ \mathit{got2stk\_R} = 110;$

$\mathit{dist}\ c_1\ c_2\ \mathit{stk2lon\_R} = 420;$

$\mathit{dist}\ c_1\ c_2\ (\mathit{join}\ c_1\ c_3\ c_2\ r_{13}\ r_{32}) = \mathit{dist}\ c_1\ c_3\ r_{13} + \mathit{dist}\ c_3\ c_2\ r_{32};$

RDF/RDFS in five sentences

- RDF/RDFS describes **resources**
- Every resource belongs to some **class**
- The descriptions are composed of **statements** which are the atomic units
- Every statement is a tripple of subject (resource), predicate (**property**) and object (**value**).
- Every class, statement, and property is also a resource.

RDF/RDFS in four sentences

$$
\begin{aligned}
&\textbf{cat}\ \mathit{Resource}\ (c : \mathit{Class});\\
&\quad \mathit{Class};\\
&\quad \mathit{Statement};\\
&\quad \mathit{Property}\ (\mathit{domain}, \mathit{range} : \mathit{Class});
\end{aligned}
$$

$$
\begin{aligned}
&\textbf{fun}\ \mathit{class} : \mathit{Class} \to \mathit{Resource}\ \mathit{class\_C};\\
&\quad \mathit{statement} : \mathit{Statement} \to \mathit{Resource}\ \mathit{statement\_C};\\
&\quad \mathit{property} : (d, r : \mathit{Class}) \to \mathit{Property}\ d\ r \to \mathit{Resource}\ \mathit{property\_C};
\end{aligned}
$$

Example Resources

Abstract Syntax

$$
\begin{aligned}
&\textbf{fun}\ \mathit{organization\_C}, \mathit{sector\_C} : \mathit{Class} \\
&\quad \mathit{digitalgrammars\_R} : \mathit{Resource}\ \mathit{organization\_C}; \\
&\quad \mathit{grammars\_sector\_R} : \mathit{Resource}\ \mathit{sector\_C}; \\
&\quad \mathit{activeInSector\_P} : \mathit{Property}\ \mathit{organization\_C}\ \mathit{sector\_C}
\end{aligned}
$$

Concrete Syntax

$$
\begin{aligned}
&\textbf{lincat}\ \mathit{Resource}, \mathit{Class} = \mathit{Str}; \\
&\quad \textbf{lin}\ \mathit{organization\_C} = \text{"http://.../protont\#Organization"}; \\
&\qquad \mathit{sector\_C} = \text{"http://.../protonu\#IndustrySector"}; \\
&\qquad \mathit{digitalgrammars\_R} = \text{"http://www.digitalgrammars.com"}; \\
&\quad \ldots
\end{aligned}
$$

The statements are also known as assertions in logic:

$$\textbf{fun } \mathit{assert} : (d, r : \mathit{Class}) \rightarrow \\ \mathit{Resource}\ d \rightarrow \mathit{Property}\ d\ r \rightarrow \mathit{Value}\ r \rightarrow \mathit{Statement};$$

here the value category is needed because the object could be a literal also:

$$\textbf{cat } \mathit{Value}\ (c : \mathit{Class});$$
$$\textbf{fun } \mathit{res} : (c : \mathit{Class}) \rightarrow \mathit{Resource}\ c \rightarrow \mathit{Value}\ c;$$
$$\mathit{lit} : \mathit{Literal} \rightarrow \mathit{Value}\ \mathit{literal\_C};$$

Example Statement

English

Digital Grammars is active in sector grammars.

RDF Abstract Syntax

assert organization_C sector_C digitalgrammars_R activeInSector_P grammars_sector_R

RDF Concrete Syntax

⟨http://www.digitalgrammars.com⟩
⟨http://.../protonu#activeInSector⟩
⟨http://www.digitalgrammars.com/grammars⟩

Class Hierarchy in OWL

Inheritance and Type Casting

$$\begin{aligned}
\textbf{cat}\ & \mathit{SubClass}\ \mathit{Class}\ \mathit{Class}; \\
& \mathit{Inheritance}\ \mathit{Class}\ \mathit{Class};
\end{aligned}$$

$$\begin{aligned}
\textbf{fun}\ \mathit{trans} : (c_1, c_2, c_3 : \mathit{Class}) \\
\rightarrow\ & \mathit{SubClass}\ c_1\ c_2 \\
\rightarrow\ & \mathit{Inheritance}\ c_2\ c_3 \\
\rightarrow\ & \mathit{Inheritance}\ c_1\ c_3
\end{aligned}$$

$$\begin{aligned}
\textbf{fun}\ \mathit{upcast} : (c_1, c_2 : \mathit{Class}) \\
\rightarrow\ & \mathit{Inheritance}\ c_1\ c_2 \\
\rightarrow\ & \mathit{Resource}\ c_1 \\
\rightarrow\ & \mathit{Resource}\ c_2
\end{aligned}$$

The Receipe

- INGREDIENTS
  1/4 cup finely chopped onion
  1 tablespoon butter or margarine
  1/4 teaspoon dried basil
  1/4 teaspoon paprika
  1/8 teaspoon garlic powder
  1 can condensed tomato soup
  1 cup milk
- DIRECTIONS
  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

The Receipe

- INGREDIENTS
  1/4 cup finely chopped onion
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The Ontology

cat $Quantity$;

fun $whole : Int \rightarrow Quantity$; -- 1

$fraction : Int \rightarrow Int \rightarrow Quantity$; -- 1/2

$whole\_plus : Int \rightarrow Int \rightarrow Int \rightarrow Quantity$; -- 1 1/2

cat $Unit$;

fun $cup, tablespoon, teaspoon, can : Unit$;

cat $Measure$;

fun $measure : Quantity \rightarrow Unit \rightarrow Measure$;

The Receipe

- INGREDIENTS
  1/4 cup finely chopped onion
  1 tablespoon butter or margarine
  1/4 teaspoon dried basil
  1/4 teaspoon paprika
  1/8 teaspoon garlic powder
  1 can condensed tomato soup
  1 cup milk
- DIRECTIONS
  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

The Ontology

cat *Product*;

fun *onion*, *butter*, *margarine*,
basil, *paprika*, *milk*, *powder*, *soup* : *Product*;

The Receipe

- INGREDIENTS
  1/4 cup finely chopped onion
  1 tablespoon butter or margarine
  1/4 teaspoon dried basil
  1/4 teaspoon paprika
  1/8 teaspoon garlic powder
  1 can condensed tomato soup
  1 cup milk
- DIRECTIONS
  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

The Ontology

$$
\begin{array}{ll}
\textbf{cat} & \mathit{Product}; \\
\textbf{fun} & \mathit{onion}, \mathit{butter}, \mathit{margarine}, \\
 & \mathit{basil}, \mathit{paprika}, \mathit{milk}, \mathit{garlic}, \mathit{tomato} : \mathit{Product}; \\
\textbf{fun} & \mathit{powder}, \mathit{soup} : \mathit{Product} \longrightarrow \mathit{Product};
\end{array}
$$

The Receipe

- INGREDIENTS
  1/4 cup finely chopped onion
  1 tablespoon butter or margarine
  1/4 teaspoon dried basil
  1/4 teaspoon paprika
  1/8 teaspoon garlic powder
  1 can condensed tomato soup
  1 cup milk
- DIRECTIONS
  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

$$\textbf{fun}\ \mathit{alternative}, \mathit{composite} : \mathit{Product} \rightarrow \mathit{Product} \rightarrow \mathit{Product};$$

The Receipe

- INGREDIENTS
  1/4 cup finely chopped onion
  1 tablespoon butter or margarine
  1/4 teaspoon dried basil
  1/4 teaspoon paprika
  1/8 teaspoon garlic powder
  1 can condensed tomato soup
  1 cup milk
- DIRECTIONS
  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

The Ontology

$\mathbf{cat}\ \ \mathit{Preparation};$

$\mathbf{fun}\ \ \mathit{chopped}, \mathit{dried}, \mathit{condensed} : \mathit{Preparation};$

$\mathbf{fun}\ \ \mathit{preparation} : \mathit{Preparation} \longrightarrow \mathit{Product} \longrightarrow \mathit{Product};$

The Receipe

- INGREDIENTS
  1/4 cup finely chopped onion
  1 tablespoon butter or margarine
  1/4 teaspoon dried basil
  1/4 teaspoon paprika
  1/8 teaspoon garlic powder
  1 can condensed tomato soup
  1 cup milk
- DIRECTIONS
  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

The Ontology

$$\textbf{cat}\ \textit{PreparationMod};$$

$$\textbf{fun}\ \textit{finely} : \textit{PreparationMod};$$

$$\textbf{fun}\ \textit{preparation\_mod} : \textit{PreparationMod} \rightarrow \textit{Preparation} \rightarrow \textit{Preparation};$$

The Receipe

- INGREDIENTS
  1/4 cup finely chopped onion
  1 tablespoon butter or margarine
  1/4 teaspoon dried basil
  1/4 teaspoon paprika
  1/8 teaspoon garlic powder
  1 can condensed tomato soup
  1 cup milk
- DIRECTIONS
  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

The Ontology

$$\textbf{cat}\ \mathit{Ingredient};$$

$$\textbf{fun}\ \mathit{ingredient} : \mathit{Measure} \rightarrow \mathit{Product} \rightarrow \mathit{Ingredient};$$

ingredient (*measure* (*fraction* 1 4) *teaspoon*) (*preparation dried basil*)	1/4 teaspoon dried basil
ingredient (*measure* (*fraction* 1 4) *teaspoon*) *paprika*	1/4 teaspoon paprika
ingredient (*measure* (*fraction* 1 8) *teaspoon*) (*powder garlic*)	1/8 teaspoon garlic powder
ingredient (*measure* (*whole* 1) *cup*) *milk*	1 cup milk

The Receipe

- INGREDIENTS

  1/4 cup finely chopped onion
  1 tablespoon butter or margarine
  1/4 teaspoon dried basil
  1/4 teaspoon paprika
  1/8 teaspoon garlic powder
  1 can condensed tomato soup
  1 cup milk

- DIRECTIONS

  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

The Ontology

Directions:

$$\begin{aligned}
&\textbf{cat}\ \ \mathit{Direction};\\
&\textbf{fun}\ \ \mathit{action} : \mathit{Action} \rightarrow \mathit{Direction};\\
&\qquad\ \ \mathit{operation} : \mathit{Operation} \rightarrow \mathit{Duration} \rightarrow \mathit{Direction};
\end{aligned}$$

The Ontology

Actions:

$$\textbf{cat}\ Action;$$
$$\textbf{fun}\ add : Product \rightarrow Action;$$

Operations:

$$\textbf{cat}\ \mathit{Operation};$$

$$\begin{aligned}
\textbf{fun}\ & \mathit{soute} : \mathit{Product} \rightarrow \mathit{Product} \rightarrow \mathit{Operation}; \\
& \mathit{stir_in} : \mathit{Product} \rightarrow \mathit{Operation}; \\
& \mathit{cook} : \mathit{Temperature} \rightarrow \mathit{Operation};
\end{aligned}$$

$$\textbf{cat}\ \mathit{Temperature};$$

$$\textbf{fun}\ \mathit{celsius} : \mathit{Int} \rightarrow \mathit{Temperature};$$

$$\textbf{fun}\ \mathit{medium\_heat} : \mathit{Temperature};$$

$$\textbf{def}\ \mathit{medium\_heat} = \mathit{celsius}\ 80;$$

The Receipe

- INGREDIENTS
  1/4 cup finely chopped onion
  1 tablespoon butter or margarine
  1/4 teaspoon dried basil
  1/4 teaspoon paprika
  1/8 teaspoon garlic powder
  1 can condensed tomato soup
  1 cup milk
- DIRECTIONS
  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

The Ontology

cat *Duration*;

fun $until : Condition \rightarrow Duration$;

$for\_time : Int \rightarrow TimeUnit \rightarrow Duration$;

cat *Condition*;

fun $tender, blended, heated : Condition$;

cat *TimeUnit*;

fun $second, minute, hour : TimeUnit$;

The Receipe

- INGREDIENTS

  1/4 cup finely chopped onion

  1 tablespoon butter or margarine

  1/4 teaspoon dried basil

  1/4 teaspoon paprika

  1/8 teaspoon garlic powder

  1 can condensed tomato soup

  1 cup milk
- DIRECTIONS

  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

The Ontology

$$\textbf{fun}\ \mathit{either} : \mathit{Duration} \to \mathit{Duration} \to \mathit{Duration};$$

The Receipe

- INGREDIENTS
  1/4 cup finely chopped onion
  1 tablespoon butter or margarine
  1/4 teaspoon dried basil
  1/4 teaspoon paprika
  1/8 teaspoon garlic powder
  1 can condensed tomato soup
  1 cup milk
- DIRECTIONS
  Saute onion in butter until tender. Add basil, paprika and garlic powder. Stir in soup and milk until well blended. Cook over medium heat for 6 minutes or until heated through.

The Ontology

$$\textbf{cat } \mathit{Receipe};$$

$$\textbf{fun } \mathit{receipe} : [\mathit{Ingredient}] \rightarrow [\mathit{Direction}] \rightarrow \mathit{Receipe};$$

Defects in Ratatui

The ontology permits some expressions which are syntactically correct but not semantically consistent.

soute onion garlic	soute onion in garlic
stir_in paprika	stir in paprika

Solution: Use **Dependent Types**

Ratatui with Dependent Types

cat Kind;

fun $\mathit{liquid}, \mathit{oil}, \mathit{firm} : \mathit{Kind}$;

cat $\mathit{Product}\ \mathit{Kind}$;

fun $\mathit{alternative}$,

$\quad \mathit{composite} : (k : \mathit{Kind}) \to \mathit{Product}\ k \to \mathit{Product}\ k \to \mathit{Product}\ k$;

fun $\mathit{add} : (k : \mathit{Kind}) \to \mathit{Product}\ k \to \mathit{Direction}$;

fun $\mathit{soute} : \mathit{Product}\ \mathit{firm} \to \mathit{Product}\ \mathit{oil} \to \mathit{Operation}$;

$\quad \mathit{stir\_in} : \mathit{Product}\ \mathit{liquid} \to \mathit{Operation}$;

Things that are not covered

- Some product could be mentioned in the description only if it is also declared in the ingredients
- The total quantity of every product in the description should be equal to the quantity in the ingredients

Ratatui to RDF

RDF Concrete Syntax

$$
\begin{array}{l}
\mathit{gf2rdf} : \mathit{Resource\ measure\_C} \rightarrow \mathit{Measure} \rightarrow [\mathit{Statement}] \\
\mathit{gf2rdf}\ \mathit{id}\ (\mathit{whole}\ v) = \\
\quad [\ \mathit{assert}\ ?\ ?\ \mathit{id}\ \mathit{hasValue}\ (\mathit{lit}\ (\mathit{int}\ v)) \\
\quad] \\
\mathit{gf2rdf}\ \mathit{id}\ (\mathit{fraction}\ m\ n) = \\
\quad [\ \mathit{assert}\ ?\ ?\ \mathit{id}\ \mathit{hasNomValue}\ (\mathit{lit}\ (\mathit{int}\ m)) \\
\quad ,\ \mathit{assert}\ ?\ ?\ \mathit{id}\ \mathit{hasDenomValue}\ (\mathit{lit}\ (\mathit{int}\ n)) \\
\quad] \\
\mathit{gf2rdf}\ \mathit{id}\ (\mathit{whole\_plus}\ v\ m\ n) = \\
\quad [\ \mathit{assert}\ ?\ ?\ \mathit{id}\ \mathit{hasValue}\ (\mathit{lit}\ (\mathit{int}\ n)) \\
\quad ,\ \mathit{assert}\ ?\ ?\ \mathit{id}\ \mathit{hasNomValue}\ (\mathit{lit}\ (\mathit{int}\ m)) \\
\quad ,\ \mathit{assert}\ ?\ ?\ \mathit{id}\ \mathit{hasDenomValue}\ (\mathit{lit}\ (\mathit{int}\ n)) \\
\quad]
\end{array}
$$

Thank You

Thank You and Have Fun !!!