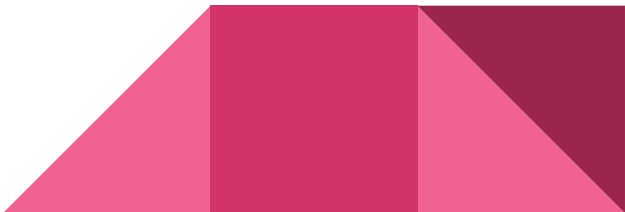


Development of a logic-based solution for selecting target ingredients and their plausible substitutes

Weronika T. Adrian, PhD, PAN Seminar, June, 2nd 2023



Agenda

- Context and Motivation
 - Knowledge engineering in food domain
 - Knowledge-based model for reasoning about substitution with ontologies and rules
 - Identifying “wrong” ingredients in recipes
 - Reasoning about substitutes
 - Summary and outlook
- 

Context and motivation



Norway
grants

[Home](#)

[Workpackages](#)

[Publications & resources](#)

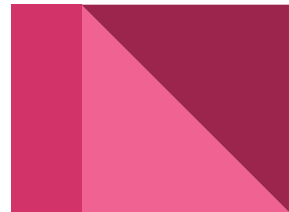
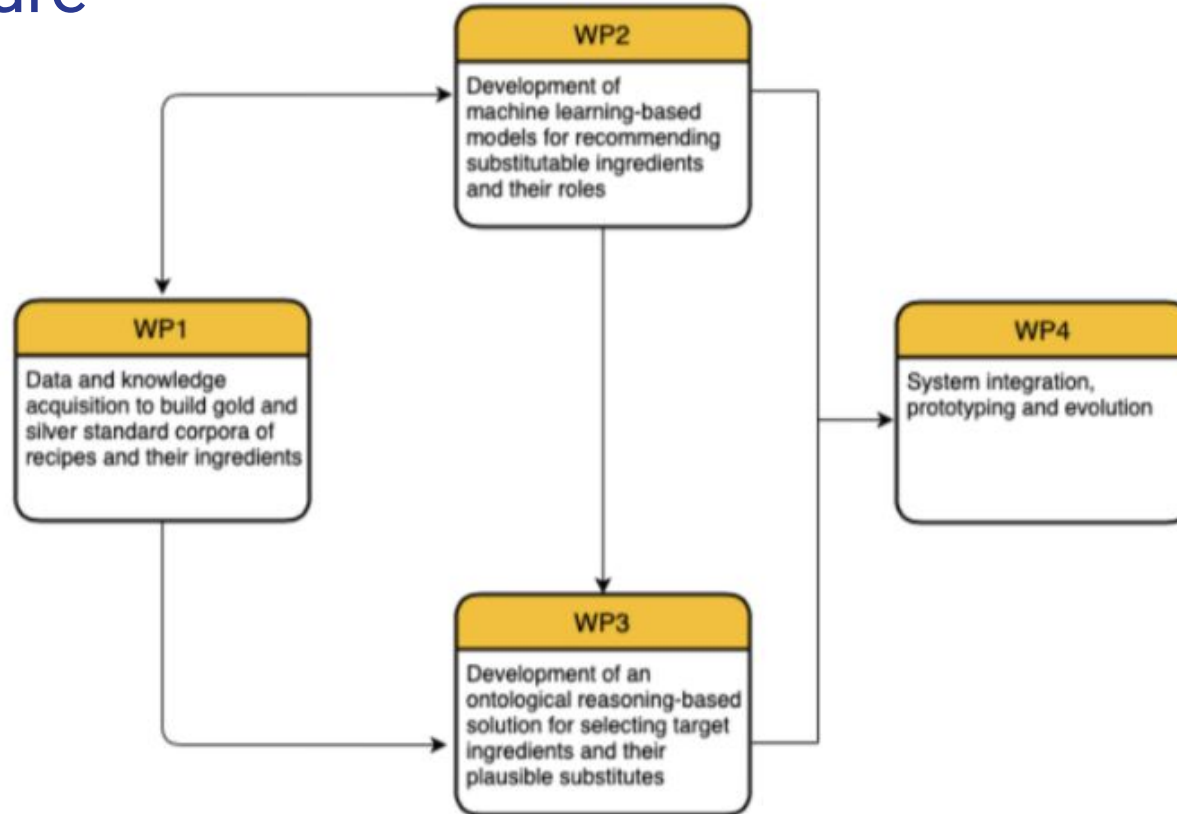
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**What ingredient to
substitute?**

WP structure



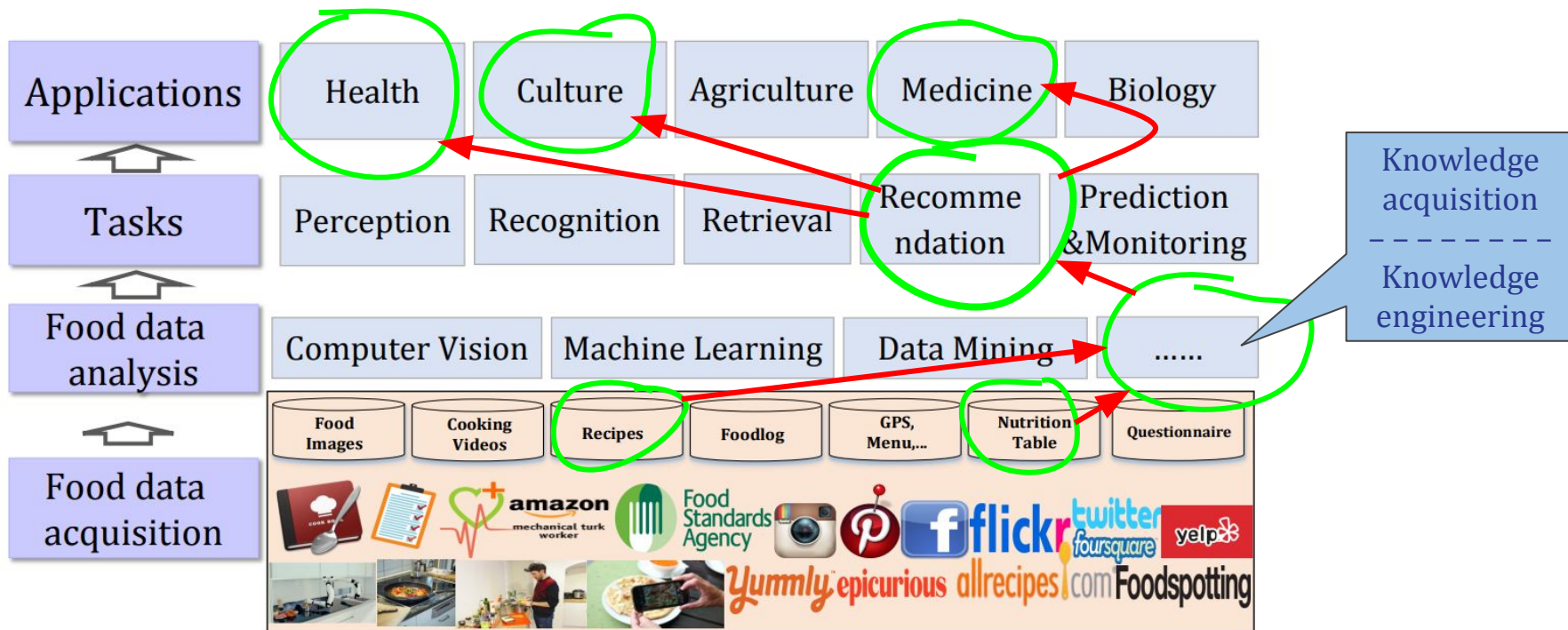
WP3 Research Objectives

1. To propose a *logic-based method* for identifying ingredients in food recipes that do not meet the specified *constraints*
 2. To propose a logic-based method for *pruning “wrong” substitutes* from a list of substitutes proposed by ML models
 3. To be able to *explain* the results of reasoning
- 



Knowledge engineering in food domain


Food computing domain



Knowledge engineering tasks

- Knowledge acquisition:
 - Work with domain experts to elicitate knowledge
 - Research available ontologies for what we need
- Knowledge modeling:
 - Formalized knowledge with rules, ontologies etc.
 - Integrate and reuse existing models
- Knowledge processing
 - Define knowledge based system that is able to transform the knowledge base (reason over it)



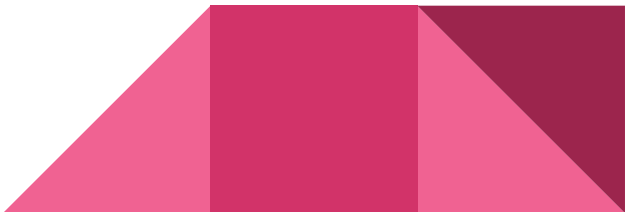


Knowledge-based model for
reasoning about substitution
with ontologies and rules

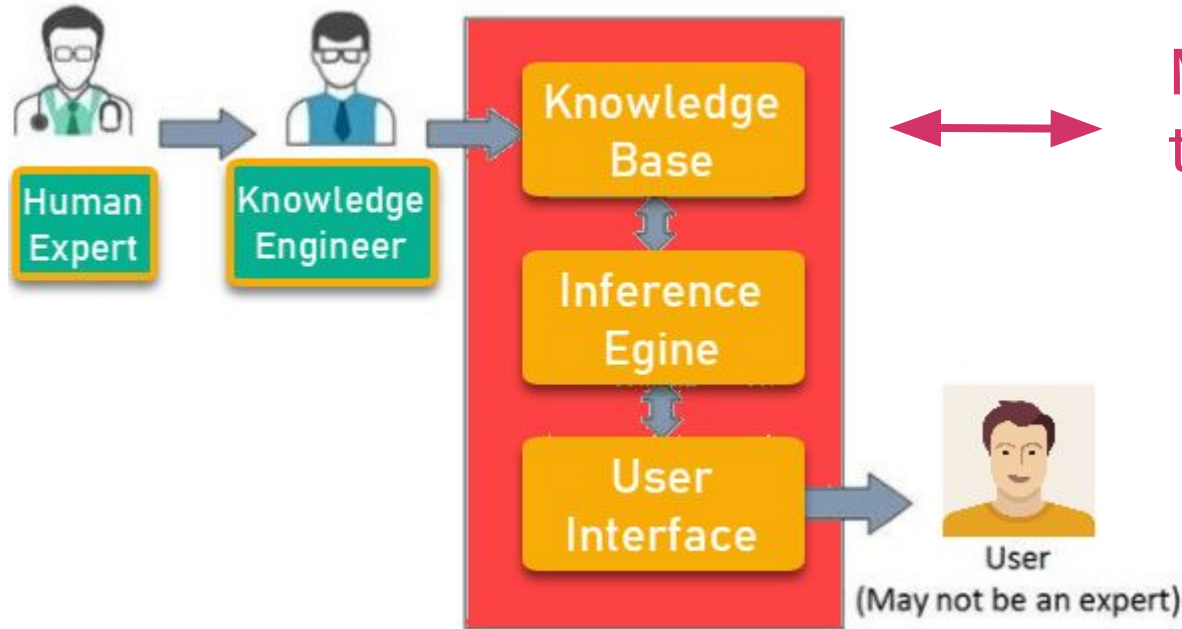
Research Objectives revisited

1. To propose a *logic-based method* for identifying ingredients in food recipes that do not meet the specified *constraints*
2. To propose a logic-based method for pruning “wrong” substitutes from a list of substitutes proposed by ML models

In fact, more questions arise from the above....

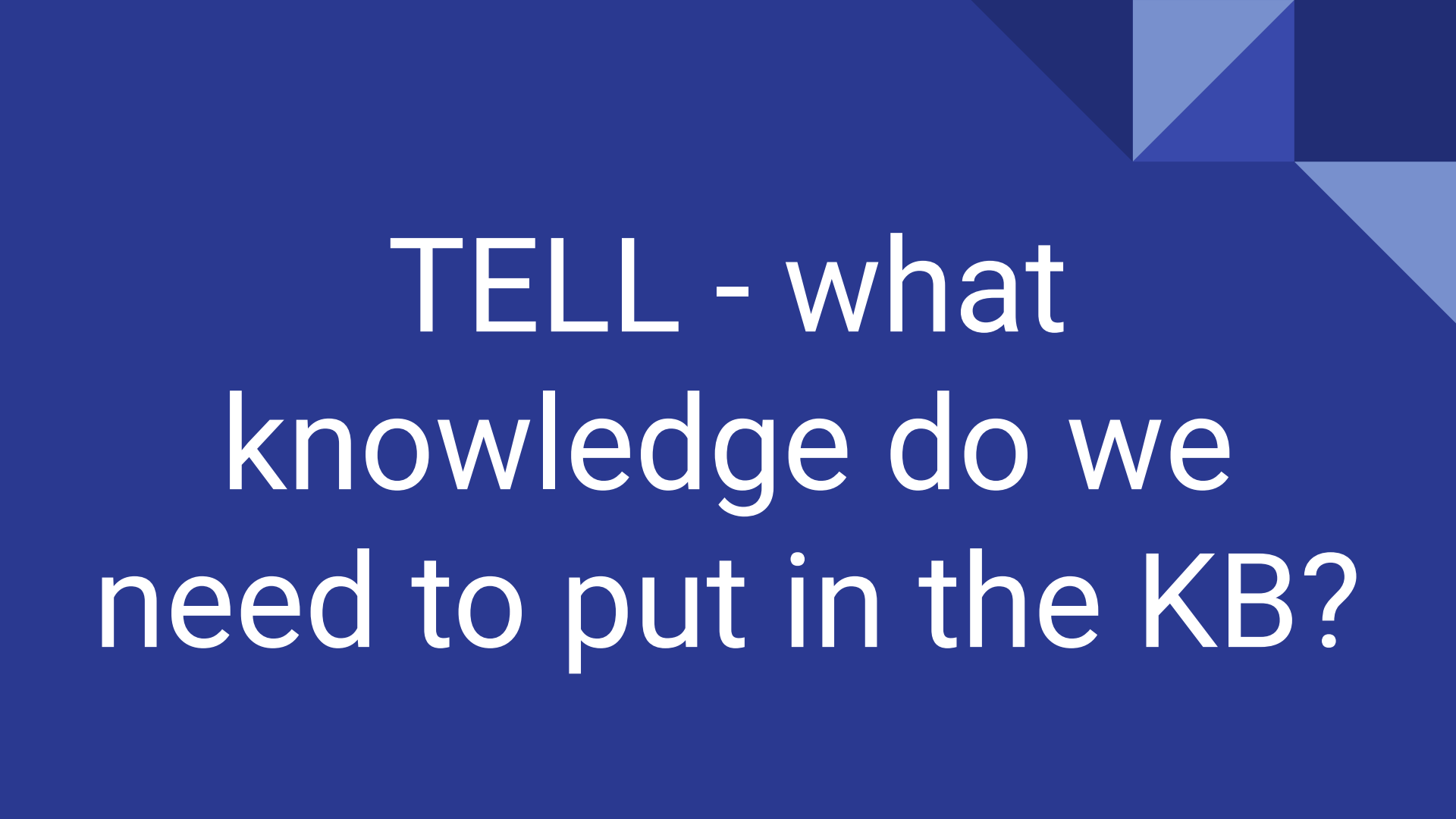
- What knowledge do we need?
 - How to model constraints (and everything else)?
 - How to reason about this knowledge?
- 

Methodology: as for a knowledge-base system



Main operations on the knowledge base:

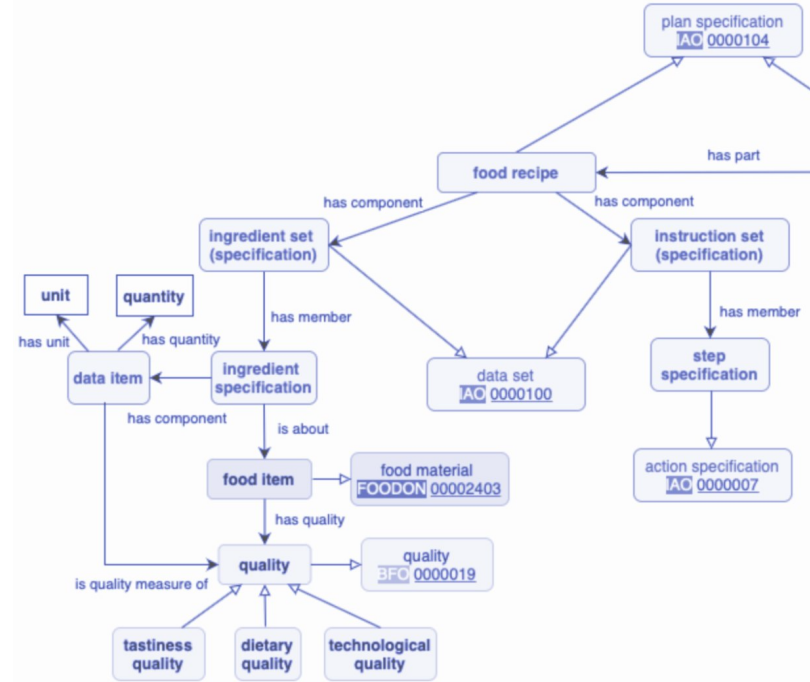
- TELL
- ASK

The background is a solid dark blue color. In the top right corner, there are several overlapping triangles in various shades of blue, creating a geometric pattern.

TELL - what
knowledge do we
need to put in the KB?

1: Recipe datasets

- Semi-structured data sources
 - Text, images
 - Ingredients sets:
 - food items + quantity (units)
 - Instructions sets (technological process)
 - Nutritional data
- Data acquisition
 - APIs
 - Crawling, web-scraping
 - Database dumps
- Annotation
- Entity linking



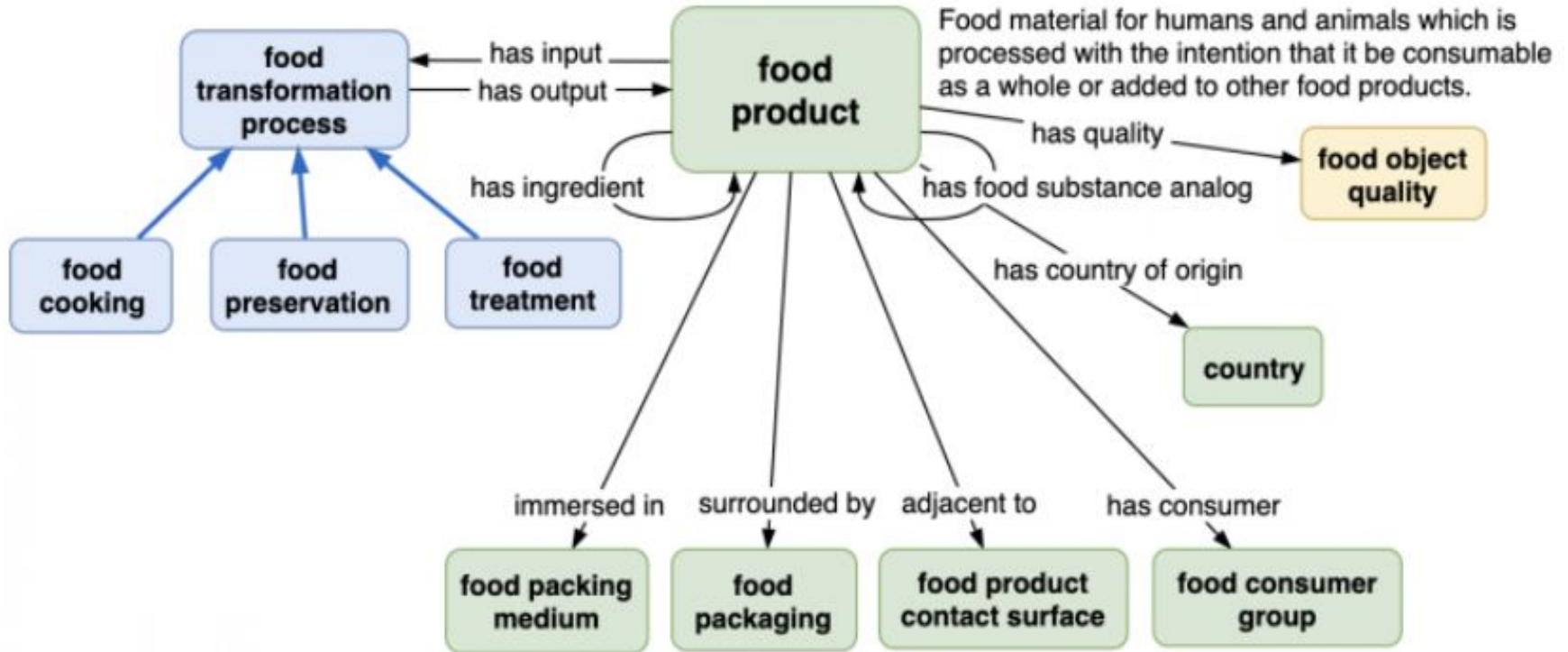
2. Food-related ontologies and knowledge graphs

- FoodOn - “A farm to fork ontology”
- Ontology for Nutritional Studies, Ontology of Nutritional Epidemiology
- Smart Products Ontology
- FoodKG - knowledge graphs with recipes
- Tables of nutritional data
- EU regulations on allergies vocabulary

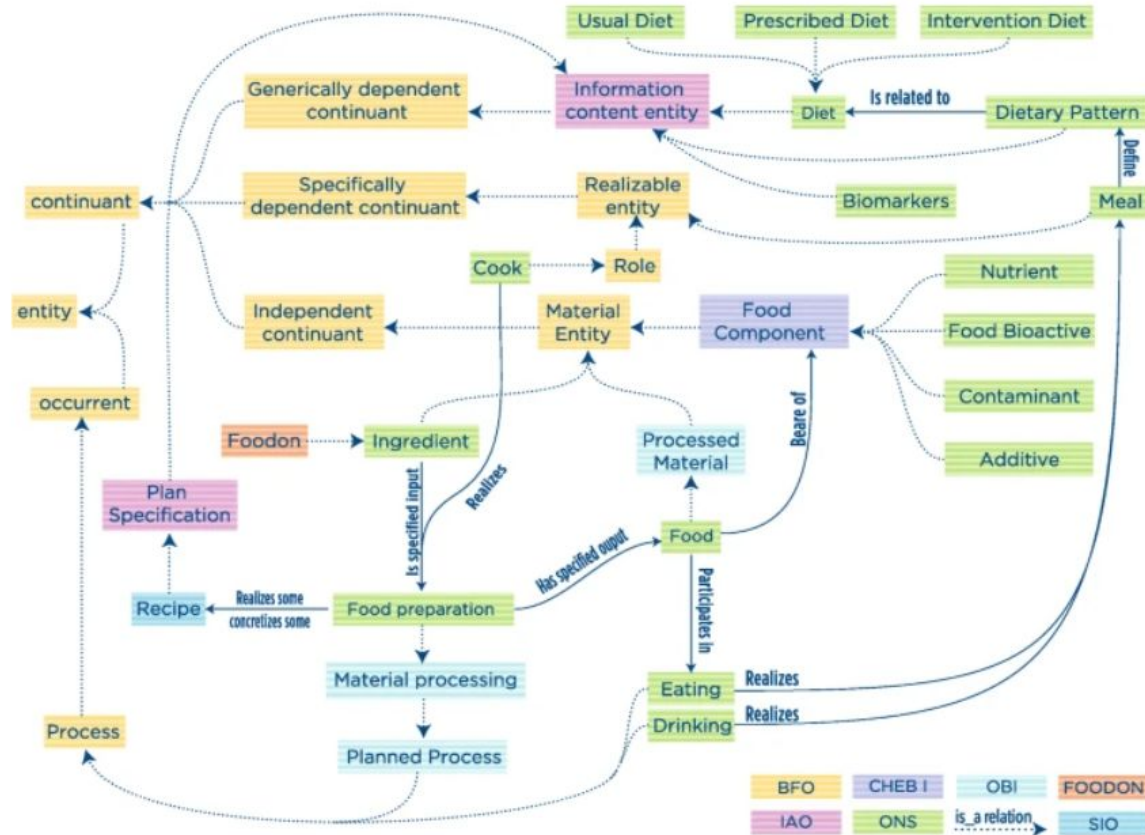
EVERYTHING IS (OR SHOULD BE) CONNECTED...



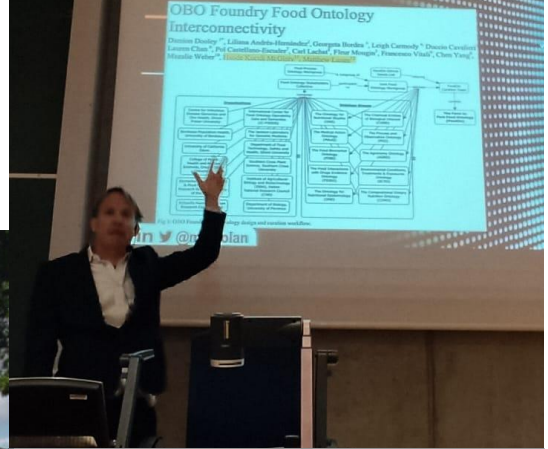
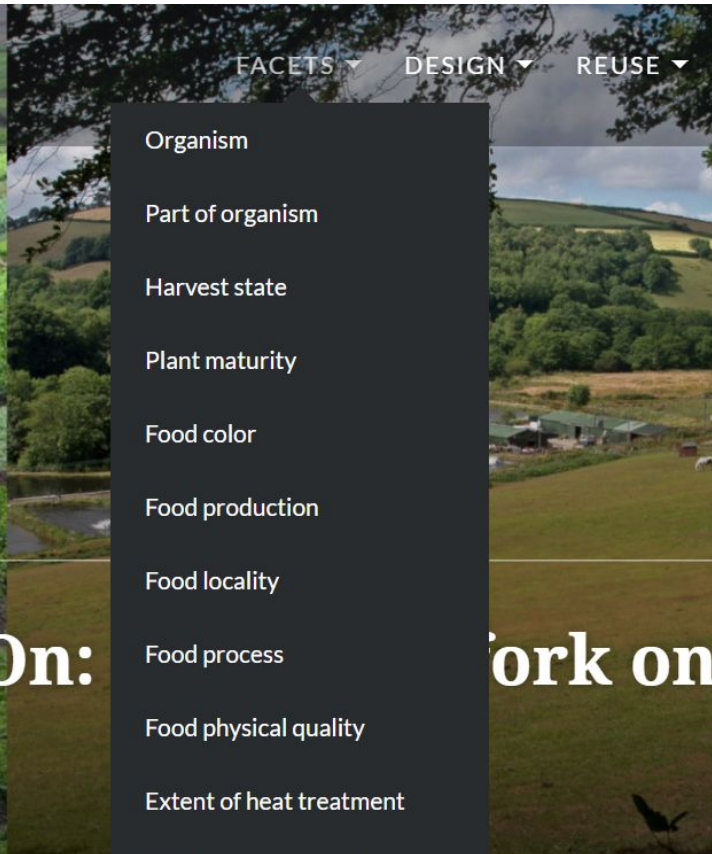
FoodOn - facets of food, from harvest to consumption



Ontology for Nutritional Studies



Towards the Internet of Food...



3. Domain experts' knowledge

- How domain experts talk:
 - “It’s not that easy...”
 - **“It depends...”**
 - “It works for baking, but not for frying...”
 - “Everything could be substituted, the possibilities are endless...”
 - “Why would one want to substitute it?”
- How to acquire and structure this knowledge?



[Scenariusz #1 - zamiana wynikająca z braku produktu; zamiennik musi odwzorowywać wartość odżywczą, tj. być również dobrym źródłem błonnika]

Persona X zdecydowała się na przygotowanie risotto. Jednak, gdy przyszło do sporządzenia potrawy okazało się, że zabrakło jej ryżu brązowego. W przepisie, który wykorzystywała nie było podanej informacji na temat składnika/składników, którymi można zastąpić ryż. Co więcej Persona X postanowiła odżywiać się zdrowo i zastanawia się, który możliwy zamiennik ryżu spełniałby jej oczekiwania, tj. nadawałby się nie tylko z technologicznego punktu widzenia, ale przede wszystkim byłby dobrym źródłem błonnika pokarmowego.

[Scenariusz #2 - zamiana wynikająca z konieczności wykluczenia konkretnego produktu z powodu zdrowotnego; zamiennik musi spełniać wymagania zdrowotne]

Persona Y postanowiła przyrządzić na imprezę urodzinową deser mleczny z owocami. Jednak okazało się, że jeden z gości ma zdiagnozowaną alergię na białko mleka krowiego i orzechy. Aby całkowicie nie rezygnować z pomysłu przygotowania słodkiej przekąski, Persona Y postanowiła wymienić mleko na inny składnik. Niestety nie ma ona pomysłu, który produkt sprawdziłby się w tym przypadku jako dobry zamiennik mleka. Mąż podsunął jej pomysł, że może to być napój migdałowy. Jednak nie jest przekonana, czy będzie on odpowiednim zamiennikiem, gdyż wspomniany gość ma zdiagnozowaną alergię na orzechy.

[Scenariusz #3 - zamiana wynikająca z konieczności wykluczenia konkretnego produktu z powodu zdrowotnego; zamiennik musi spełniać wymagania technologiczne, tj. musi nadawać taką samą słodkość potrawie, jak cukier]

Persona Z jest w trakcie przygotowania nieczonych ciasteczek na spotkanie rodzinne. Dowiedziała się jednak

Domain experts' sources...

Gluten w spożywczych zastosowaniach pozapiekarskich

Typ produktu	Zawartość glutenu %	Typ produktu	Zawartość glutenu %
Analogi owoców morza	1.3	Restrukturyzowane steki wołowe	3.6
Analogi mięsa krabiego	2.1	Frankfurterki	8
Analogi kawioru	1-30	Przekąski wysokobiałkowe	1-50
Analogi kielbasek	8-17	Pasty wysokobiałkowe	1.6
Analogi pulpetów i hamburgerów	10.6	Tortille	1-4
Imitacje serów	5.8-14.2	Ekstrudowane produkty błonnikowe z glutenem	20-23

(30). Pokazano w przeliczeniu na gini.

▼ M2

12.1.2

Substytuty soli

Grupa I	Dodatki			
E 338–452	Kwas fosforowy – fosforany – di-, tri- i polifosforany	10 000	(1) (4)	

▼ M2

Numer kategorii	Numer E	Nazwa	Maksymalny poziom (odpowiednio mg/l lub mg/kg)	Przypisy	Ograniczenia/wyjątki
-----------------	---------	-------	--	----------	----------------------

▼ M7

	E 535–538	Żelazocyjanki	20	(1) (57)	
	E 551–559	Dwutlenek krzemu – krzemiany	20 000		Okres stosowania: do dnia 31 stycznia 2014 r.
	E 551–553	Dwutlenek krzemu – krzemiany	20 000		Okres stosowania: od dnia 1 lutego 2014 r.
	E 620–625	Kwas glutaminowy – glutaminy	<i>quantum satis</i>		
	E 626–635	Rybonukleotydy	<i>quantum satis</i>		
		(1): Dodatki mogą być dodawane pojedynczo lub łącznie.			
		(4): Maksymalny poziom podano w przeliczeniu na P ₂ O ₅ .			
		(57): Maksymalny poziom podano w przeliczeniu na bezwodny żelazocyjanek potasu.			

▼ M2

Domain experts' analyses...

B	C	D	E	F	G	H	I	J	K	L	M	N
https://www.allrecipes.com/recipe/16354/easy-meatloaf/												
Easy Meatloaf / mielony - pieczeń rzymska												
1 ½ pounds ground beef	mielona wołowina											
1 egg	jajo											
1 onion, chopped	cebula											
1 cup milk	mleko											
1 cup dried bread crumbs	bułka tarta / krakersy											
salt and pepper to taste	sól i pieprz											
2 tablespoons brown sugar	brązowy cukier											
2 tablespoons prepared mustard	musztarda											
½ cup ketchup	keczup											
Step 1												
Preheat oven to 350 degrees F (175 degrees C).												
Step 2												
In a large bowl, combine the beef, egg, onion, milk and bread OR cracker crumbs. Season with salt and pepper to taste and place in a lightly greased 9x5-inch loaf pan, or form into a loaf and place in a lightly greased 9x13-inch baking dish.												
Step 3												
In a separate small bowl, combine the brown sugar, mustard												


```
graph TD; WOLOWINA --> ROZGRZAĆ; JAJO --> POŁĄCZYĆ_SKŁADNIKI; CEBULA --> POŁĄCZYĆ_SKŁADNIKI; MLEKO --> POŁĄCZYĆ_SKŁADNIKI; BUŁKA_TARTA --> POŁĄCZYĆ_SKŁADNIKI; SÓL --> POŁĄCZYĆ_SKŁADNIKI; PIEPRZ --> POŁĄCZYĆ_SKŁADNIKI; CUKIER_BRĄZOWY --> POŁĄCZYĆ_SKŁADNIKI; ROZGRZAĆ --> POŁĄCZYĆ_SKŁADNIKI; POŁĄCZYĆ_SKŁADNIKI --> UŁOŻYĆ_W_BLASZCIE; UŁOŻYĆ_W_BLASZCIE --> POŁAĆ_WIERZCH; POŁĄCZYĆ --> POŁAĆ_WIERZCH; POŁAĆ_WIERZCH --> PIEC_1H_175C; style POŁĄCZYĆ fill:none,stroke:none; style PIEC_1H_175C fill:none,stroke:none;
```

Domain experts' analyses...

SKŁADNIKI PODSTAWOWE	ZAMIEŃ NA:	WARUNEK 1:	WARUNEK 2:	WARUNEK 3 [STOSUNEK ZAMIANY]:	
wołowina mielona	wieprzowina	na zimno: TAK	pieczenie: TAK	1:1	
	kurczak	na zimno: TAK	pieczenie: TAK	1:1	
	indyk	na zimno: TAK	pieczenie: TAK	1:1	
	łosoś biały	na zimno: TAK	pieczenie: TAK	1:1	
	tuńczyk	na zimno: TAK	pieczenie: TAK	1:1	
	ciecierzyca	ugotowana	pieczenie: TAK	1:1	
	soczewica	ugotowana	pieczenie: TAK	1:1	
	tempeh	na zimno: TAK	pieczenie: TAK	1:1	
	soja	ugotowana	pieczenie: TAK	1:1	
	sojowe kotlety	na zimno: TAK	pieczenie: TAK	1:1	
	fasola	ugotowana	pieczenie: TAK	1:1	
	grzyby	na zimno: TAK	pieczenie: TAK	1:1	
	Seitan (gluten pszenny)	na zimno: TAK	pieczenie: TAK	1:1	
	białko z owadów	na zimno: TAK	pieczenie: TAK	1:1	
	bakłażan	na zimno: TAK	pieczenie: TAK	1:1	
jajo	jajo w proszku	na zimno: TAK	pieczenie: TAK	1:1	
	len mielony	na zimno: TAK	pieczenie: TAK	1:1	plus woda 100%
	chia mielona	na zimno: TAK	pieczenie: TAK	10g:1szt	plus woda 100%
	agar agar	na zimno: TAK	pieczenie: TAK	5g:1 szt	plus woda 100%

Pieczeń rzymska mielony SCHEMAT

Pieczeń - ZAMIENNIKI

Wieprzowina- KARTA PRODUKTU

... (+) :



Domain experts' analyses...

Wieprzowina	zależy który element kulinarny							
ETYKIETY OGÓLNE:	LEKKOSTRAWNY NIE	BEZGLUTENOWY TAK	WEGETARIAŃSKI NIE	WEGAŃSKI NIE	BEZ LAKTOZY TAK			
ETYKIETY TECHNOLOGICZNE:	NA SUROWO NIE	DO GOTOWANIA TAK	DO SMAŻENIA TAK	DO PIECZENIA TAK				
ETYKIETY ODŻYWCZE:	ŹRÓDŁO: żelazo, białko		MAŁO: <u>witaminy</u>	KALORIE: <u>120</u>				
MOŻLIWA ZAMIANA NA:	wieprzowina	kurczak	indyk	łosoś biały	tuńczyk	ciecierzyca	soczewica	tempeh
warunek 1 [stosunek zamiany]:	1:1	1:1	1:1	1:1	1:1	1:1	1:1	
warunek 2:	na zimno: TAK	na zimno: TAK	na zimno: TAK	na zimno: TAK	na zimno: TAK	ugotowana	ugotowana	na zimno
warunek 3:								
warunek 4:								
warunek 5:								
UWAGA DODATKOWA/KOMENTARZ:								



C37 fx 1 cup heavy cream

	A	B	C	D	E	F	G
1	Title	Link	Ingredient	Vegetarian (ratio)	Vegetarian (food product)	Vegan (ratio)	Vegan (food product)
3	Yellow Bird	https://www.food.com/recipe/yellow-bi	4 ounces triple sec				
4	Yellow Bird	https://www.food.com/recipe/yellow-bi	3 ounces Tia Maria				
5	Yellow Bird	https://www.food.com/recipe/yellow-bi	20 ounces orange juice				
6	Cinnamon Roll French Toast	https://tasty.co/recipe/cinnamon-roll-fre	2 tubes cinnamon roll, refrigerated, with icing				
7	Cinnamon Roll French Toast	https://tasty.co/recipe/cinnamon-roll-fre	4 tablespoons butter, melted	1:1	margarine	1:1	ma
8	Cinnamon Roll French Toast	https://tasty.co/recipe/cinnamon-roll-fre	6 eggs				
9	Cinnamon Roll French Toast	https://tasty.co/recipe/cinnamon-roll-fre	1/2 cup milk	1:1	oat drink	1:1	o
10	Cinnamon Roll French Toast	https://tasty.co/recipe/cinnamon-roll-fre	2 teaspoons cinnamon				
11	Cinnamon Roll French Toast	https://tasty.co/recipe/cinnamon-roll-fre	2 teaspoons vanilla				
12	Cinnamon Roll French Toast	https://tasty.co/recipe/cinnamon-roll-fre	1 cup maple syrup				
13	Bahamian Sky Juice	https://www.food.com/recipe/bahamiar	4 ripe coconuts				
14	Bahamian Sky Juice	https://www.food.com/recipe/bahamiar	1 cup evaporated milk				1 cup tables milk
15	Bahamian Sky Juice	https://www.food.com/recipe/bahamiar	1 cup gin				
16	Bahamian Sky Juice	https://www.food.com/recipe/bahamiar	3 tablespoons sugar (optional)				
17	Bahamian Sky Juice	https://www.food.com/recipe/bahamiar	1 teaspoon ground cinnamon				
18	Bahamian Sky Juice	https://www.food.com/recipe/bahamiar	1/2, 2 teaspoon freshly grated nutmeg				
19	Patriot S'mores	https://www.food.com/recipe/patriot-sn	1 sheet graham cracker (broken in half)				
20	Patriot S'mores	https://www.food.com/recipe/patriot-sn	2 pieces milk chocolate candy bars	1:1	dark chocolate	1:1	dark
21	Patriot S'mores	https://www.food.com/recipe/patriot-sn	1 marshmallow				

B Bartek K
 5:41 PM Mar 28
 jak ująć w tabeli, gdy jeden składnik jest zamieniany na dwa inne i np. potrzeba dodatkowego sposobu przygotowania?

1 cup water + 6 tablespoons soy milk powder

Weronika T. Ad...

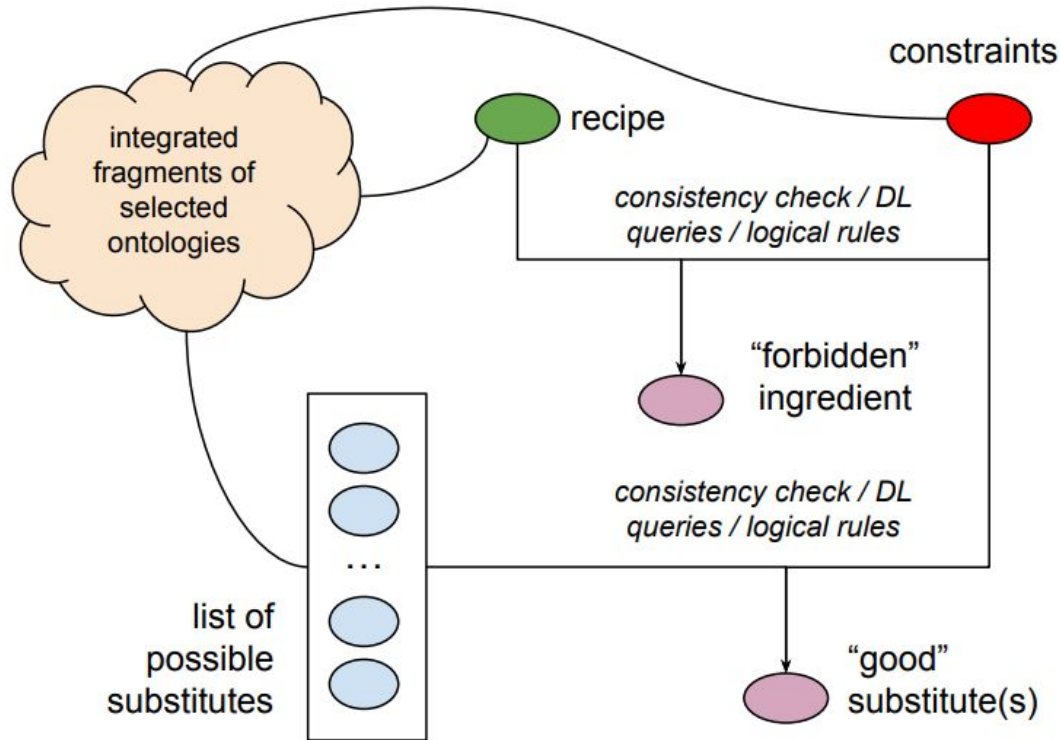
Weronika T. Adrian

Agnieszka Lawrynowicz

Jędrzej

Agnieszka

Overview of the proposed logic-based model



Current works:

1. Knowledge graph / ontology design
2. Population with instances
3. Modeling rules and DL queries

Knowledge graph/ontology design

Classes:

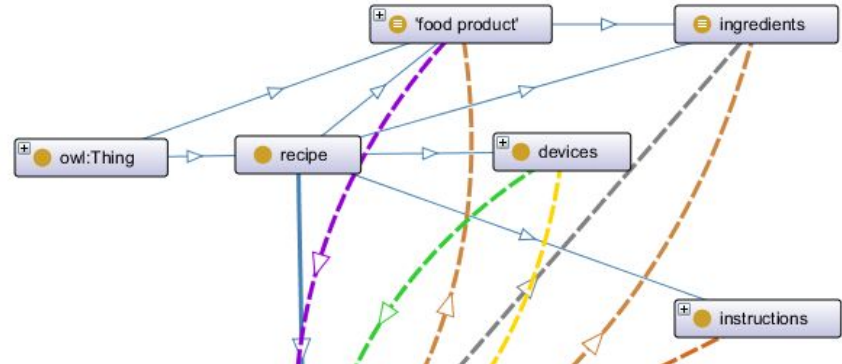
- Recipe
- Ingredient spec.
- Food product
- Diet
- Allergy

Object properties:

- acceptableIn - (food product → diet)
- unacceptableIn - food product/recipe → diet
- hasAllergicTrigger - (food product → allergy)
- hasIngredient/isNeededFor - (food product ↔ recipe name)
- isSubstituteFor - food product → food product
- useFor - instructions (specific steps) → recipe name

Data properties:

- *hasCalorificContentValue*
- *hasCarbohydratesContentValue*
- *hasFatContentValue*
- *hasProteinContentValue*
- *hasVitaminsContentValue*



Ontology imports and populating with instances

The screenshot displays a web-based ontology editor interface. The top navigation bar includes 'File', 'Edit', 'View', 'Reasoner', 'Tools', 'Refactor', 'Window', and 'Help'. The address bar shows the URL 'subFoodV2 (http://www.semanticweb.org/subFoodV2)'. Below the address bar, the breadcrumb path is '> diet > diet by nutritional composition > low-carbohydrate, high-protein, high fat diet'. The main interface is divided into several panes:

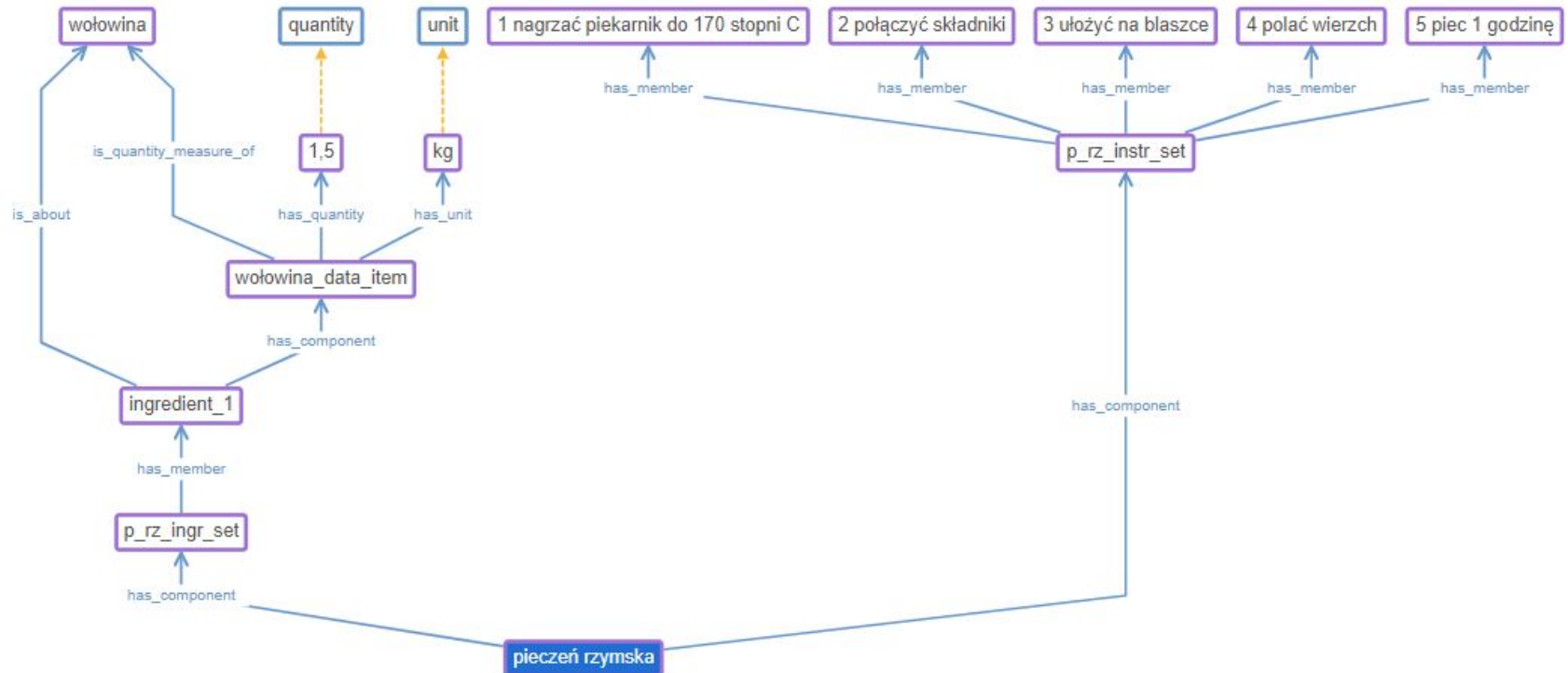
- Class hierarchy: low-carbohydrate, high-protein, high fat diet**: A tree view showing the hierarchy of classes. The 'diet' class is expanded to show its subclasses: 'diet by nutritional composition' and 'diet by type of food'. 'diet by nutritional composition' includes subclasses like 'DASH diet', 'globalized diet', 'gluten free', 'high fat diet', and 'high-carbohydrate diet'. 'diet by type of food' includes subclasses like 'diet by food organism' (with further sub-classes like 'infant breast milk diet', 'infant formula milk diet', 'lacto-ovo vegetarian diet', etc.) and 'food material' (with sub-classes like 'food product analog', 'food product by organism', etc.).
- Class hierarchy: diet by type of food**: A similar tree view, currently showing the 'diet by type of food' class and its subclasses.
- Annotations**: A section showing the annotations for the selected class. It includes:
 - rdfs:label**: low-carbohydrate, high-protein, high fat diet
 - IAO_0000115** [language: en]: Low-carbohydrate diets restrict carbohydrate consumption relative to the average diet. Foods high in carbohydrates (e.g., sugar, bread, pasta) are limited, and replaced with foods containing a higher percentage of fat and protein (e.g., meat, poultry, fish, shellfish, eggs, cheese, nuts, and seeds), as well as low carbohydrate foods (e.g. spinach, kale, chard, collards, and other fibrous vegetables).
 - rdfs:seeAlso**: https://en.wikipedia.org/wiki/Low-carbohydrate_diet
 - rdfs:seeAlso**: PMID:18635428
 - hasExactSynonym** [language: en]: (empty)
- Description: low-carbohydrate, high-protein, high fat diet**: A section showing the description and relationships of the class.
 - Equivalent To**: (empty)
 - SubClass Of**: 'diet by nutritional composition'
 - General class axioms**: (empty)

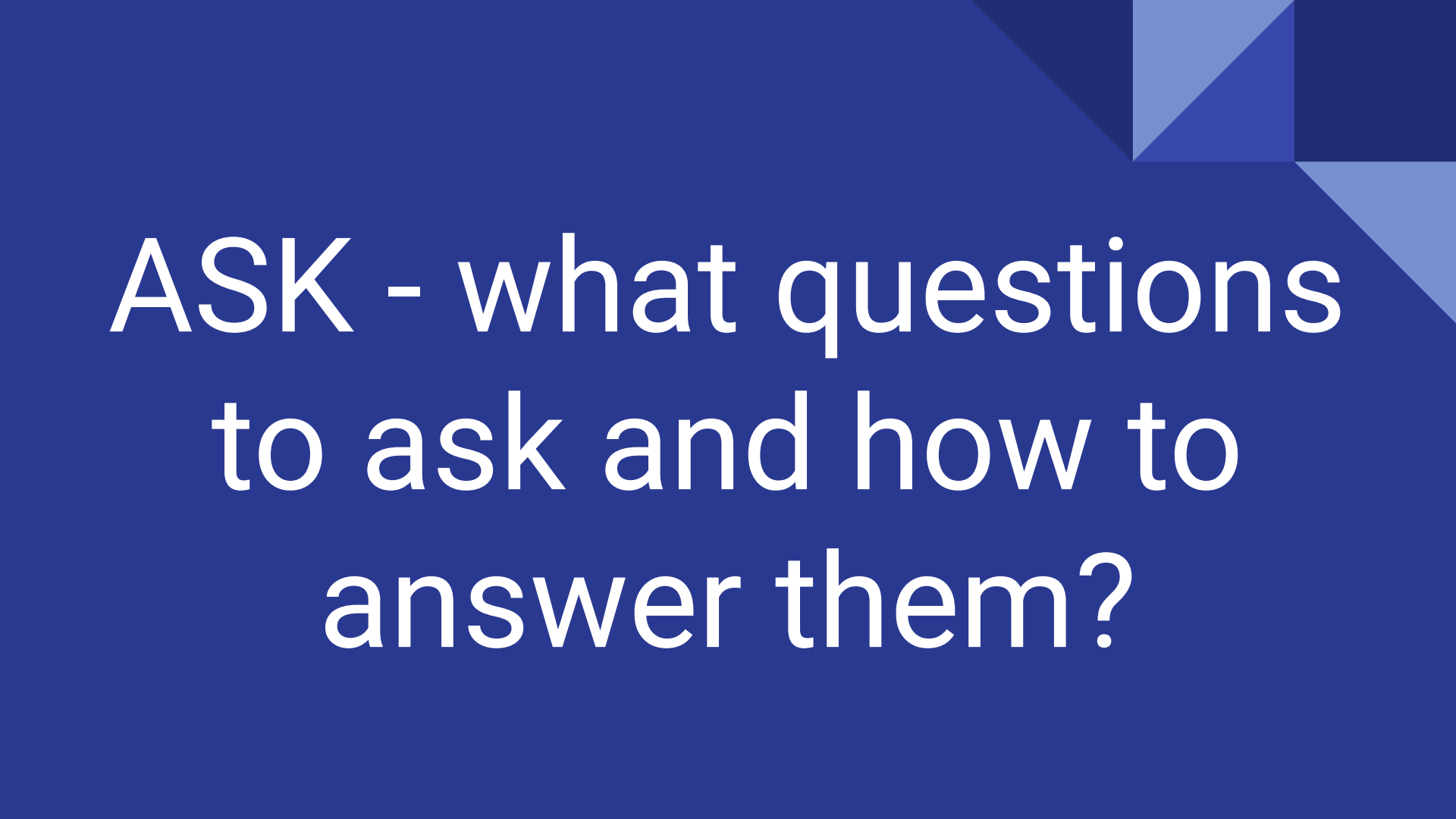
Ontology imports and populating with instances

The screenshot displays the Protege ontology editor interface for the 'subFoodV2' ontology. The main window is divided into several panes:

- Class Hierarchy:** A tree view on the left showing the hierarchy of classes. The 'ingredient specification' class is selected and highlighted in blue. Other classes include 'allergy', 'data set', 'device specification', 'diet', 'food material', 'grain plant', 'plan specification', 'food recipe', and 'step specification'.
- Active Ontology:** The top bar shows the active ontology is 'subFoodV2' (http://www.semanticweb.org/subFoodV2).
- Annotations:** The 'Usage' tab is active, showing the usage of the selected class. It displays 'Usage: california garlic salt ingredient specification'.
- Individuals:** The 'Direct instances' tab is active, showing a list of instances for the selected class. The instances are: 'black pepper ingredient specification', 'butter-flavored cooking spray ingredient specification', 'buttermilk ingredient specification', 'california garlic salt ingredient specification' (highlighted in blue), 'fish fillets ingredient specification', 'panko breadcrumbs ingredient specification', and 'paprika ingredient specification'.
- Search Results:** The 'Show: this different' section displays search results for the selected class. It found 9 uses of 'california garlic salt ingredient specification', including 'air fried sunfish ingredient set' and 'california garlic salt ingredient specification'.

Ontology imports and populating with instances



The background is a solid dark blue color. In the top right corner, there are several overlapping triangles in lighter shades of blue, creating a geometric pattern.

ASK - what questions
to ask and how to
answer them?

Main knowledge representation and reasoning methods

- Ontological queries - asking about given recipes vs. constraints
- Answer Set Programming - a full-fledged logic program
- Implementation:
 - Protege + integrated reasoner
 - DaRLing OWL2 rewriter for ASP



Modeling rules and DL queries (1a)

High-level queries for identifying forbidden/dangerous ingredients

For given *recipe:Recipe* and *my_diet:Diet*, we obtain an unacceptable ingredient **a**

```
FoodProduct(a) AND Recipe(recipe) AND Diet(my_diet) AND  
isNeedeFor(a, recipe) AND unacceptableIn(a, my_diet)
```

For given *recipe:Recipe* and *my_allergy:Allergy*, we obtain an unacceptable ingredient **a**

```
FoodProduct(a) AND Recipe(recipe) AND Allergy(my_allergy) AND  
isNeedeFor(a, recipe) AND hasAllergicTrigger(a, my_allergy)
```

Modeling rules and DL queries (1b)

Low-level diet/allergy specific rules defined for particular cases, e.g.:

- Diet excluding certain classes of products:
 - `isSubclassOf(a, meat) => isUnacceptableFor(a, vegan_diet)`
- Allergies for certain food products:
 - `isSubclassOf(a, seafood) => hasAllergicTrigger(a, seafood_allergy)`
- ...

Modeling rules and DL queries (2a)

High-level queries for pruning “wrong” substitutes

For a given *recipe:Recipe*, *my_diet:Diet* and *isSubstitute(a,b)*

```
FoodProduct(a) AND Recipe(recipe) AND isNeededFor(a, recipe)  
AND FoodProduct(b) AND isSubstituteFor(a,b)  
AND Diet(my_diet) AND unacceptableIn(b, my_diet)
```

For a given *recipe:Recipe* and *my_allergy:Allergy*

```
FoodProduct(a) AND Recipe(recipe) AND isNeededFor(a, recipe)  
AND FoodProduct(b) AND isSubstituteFor(a,b)  
AND Diet(my_diet) AND hasAllergicTrigger(b, my_allergy)
```

Modeling rules and DL queries (2b)

Low-level diet/allergy specific rules defined for particular cases, e.g.:

Potential substitutes can be assumed to be given or defined explicitly based on selected features:

```
FoodProduct(a) and FoodProduct(b) AND hasFunction(a, f) AND  
hasFunction(b, f) => isSubstituteFor(a, b)
```

```
FoodProduct(a) and FoodProduct(b) AND hasSomeFeature(a, f) AND  
hasSomeFeature(b, f) => isSubstituteFor(a, b)
```


...

Logic model in Answer Set Programming

Answer Set Programming

- Declarative programming paradigm
- Non-monotonic reasoning and logic programming
- Stable model semantics

Expressive KR language

- Roots in Datalog
 - Default negation, disjunction, constraints, aggregates
 - Weak constraints, functions, lists, sets, exist.quantifiers
- 

Hard and weak constraints in ASP


Absolutely forbidden ingredients:


```
:- foodProduct(X), recipe(Recipe), allergy(my_allergy),  
isNeededFor(X, Recipe), hasAllergicTrigger(X, My_allergy).
```

“If possible, avoid...” / “Optimize quantity of...”:

```
:-~ foodProduct(X), recipe(Recipe), diet(My_diet), isNeededFor(X,  
Recipe), unacceptableIn(X, My_diet). [1]
```

```
:-~ foodProduct(Y), recipe(Recipe), diet(My_diet), isNeededFor(Y,  
Recipe), unacceptableIn(Y, My_diet). [2]
```





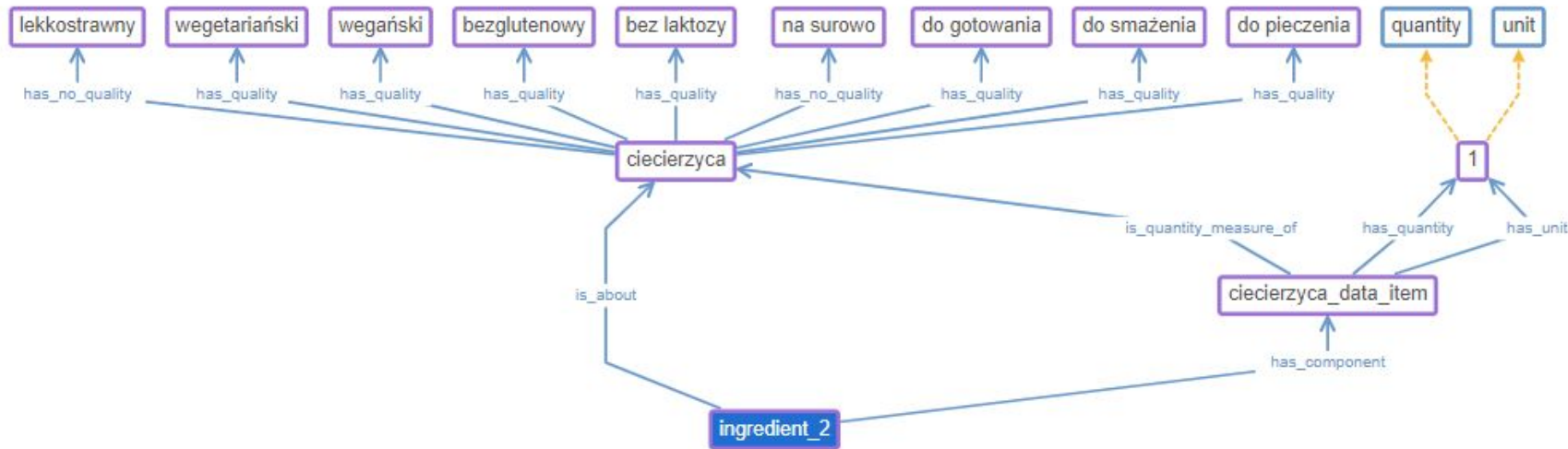
Summary and outlook

Summary and outlook

- Interdisciplinary TAISTI project (<http://taisti.eu>)
- Knowledge engineering problems in the project
 - Knowledge acquisition from domain experts (defining excel templates, etc.)
 - Knowledge **integration** reusing existing sources (defining a domain knowledge graph)
 - Knowledge **modeling** and **reasoning**
- Recent work and results
 - Knowledge-based **model** of reasoning about substitution (based on ontologies and logic programming)
 - **KB schema and high-level rules** over the knowledge graph
- Future work
 - Expanding the **rule base** about diets and allergies
 - **Implementation** of the system with DaRLing reasoner

Future refinements:
 data preparation for
 substitution as seen by
 food technologists and
 dieticians

KARTA PRODUKTU DLA CIECIERZYCY				
Etykiety ogólne				
lekkostrawny	bezglutenowy	wegetariański	wegański	bez laktozy
NIE	TAK	TAK	TAK	TAK
Etykiety technologiczne				
na surowo	do gotowania	do smażenia	do pieczenia	
NIE	TAK	TAK	TAK	
Etykiety odżywcze				
źródło	mało	kalorie		
białko, węglowodany	witaminy	120		



Thank you for your attention!

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KRAKEN



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