NutriLink: An Ontology for Linking Digital Receipts to Food Nutrition Information and Dietary Recommendations

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Abstract. Unhealthy diets are a major modifiable risk factor for non-communicable diseases (NCDs), the leading cause of morbidity and mortality world-wide. Diet monitoring, crucial for understanding and preventing unhealthy diets, often relies on self-reporting, which is burdensome, error-prone, and ineffective for long-term tracking. Enriched with product nutrition information, digital receipts from loyalty cards have created new possibilities for diet monitoring. Current regulations allow access to digital receipts with users' consent and mandate food nutrition information provision, providing a solid legislative foundation for sharing and using digital receipts in nutrition-related studies and beyond. Building on this foundation, shared ontologies can facilitate effective management and exchange of digital receipts and food product information from various sources for diverse applications. While several ontologies are available for describing food products or digital receipts individually, an ontology that can describe *enriched* digital receipts at product and basket levels, including detailed nutrition metrics, is missing today. In this paper, we present NutriLink, an ontology that links digital receipts to comprehensive nutrition details of recorded products, and further to structured dietary recommendations. This permits evaluating the nutritional quality of food purchases within and across baskets, enabling provisioning of structured dietary recommendations to users. The NutriLink ontology is linked to established ontologies, including FoodOn, GoodRelations, and AGROVOC, as well as schema.org concepts, to enhance interoperability. We showcase the value of NutriLink through its role in powering a currently active fully automated dietary counseling system with 76 users in a controlled study. NutriLink is freely and openly available, offering a structured and standardized knowledge base to researchers, practitioners—including healthcare professionals—in nutrition and related fields.

Keywords: Food ontology, Food semantics, Digital receipts, Semantic technologies

1. Introduction

The four leading non-communicable diseases (NCDs) - cardiovascular diseases, cancers, chronic respiratory diseases, and diabetes – are the leading cause of morbidity and mortality world-wide [56]. Diabetes alone led to 1.6 million deaths in 2021 [55], and it can cause blindness, kidney failure, heart attacks, stroke,

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and limb amputation [55]. The number of people living with diabetes has increased rapidly from 200 million in 1990 to 830 million in 2022 [55]. The global economic burden projected to reach USD 2.5 trillion by 2030 - nearly double the cost of USD 1.3 trillion in 2015 [4]. A major modifiable behavioral risk factor contributing to NCDs is unhealthy diets, including excess salt, sugar, and fats [56]. To understand and prevent unhealthy diets and hence NCDs, diet monitoring is pivotal. However, current diet monitoring tools typically rely on self-reported data such as food diaries and food records captured via applications [10, 51]. They are prone to recall bias and require substantial effort [3, 17, 36]. These limitations hinder the design of effective and sustainable interventions.

Grocery receipts, particularly digital receipts from loyalty cards, have the potential to revolutionize diet monitoring by integrating food composition data [35, 37, 46, 57]. Regulations like General Data Protection Regulation (GDPR) [14] (see Article 20) grant individuals the right to access and transfer their personal data—including historic and up-to-date digital receipts on loyalty cards—in both human- and machine-readable formats. Similar regulations and standards are proliferating world-wide, from the data portability rights that are part of the California *Consumer Privacy Rights Act* [28] to the People's Republic of China *Personal Information Security Specification*. [1] This paves the way for fully automated nutrition assessment and monitoring, benefiting both healthy individuals wishing to improving their diets and patients with medical needs, such as those who have undergone bariatric surgery [48]. Compared to current diet monitoring tools based on self-reporting, digital receipts substantially reduce the reporting effort (manually logging and transcribing). However, they generally lack product (nutrition) information necessary for further analysis. Bridging this gap, European Union (EU) Regulation No.1169/2011 [13] has mandated the provision of nutrition information for all food products intended for sale to final consumers, including pre-packaged and non-pre-packaged foods, as well as foods sold in restaurants. While it does not explicitly require food nutrition information to be provided in digital formats, many food manufacturers, retailers, and crowdsourced food composition databases (FCDs), such as Open Food Facts, [2] now provide such data. These developments facilitate easier access to digital food nutrition information, increasing the potential of real-time, automated diet monitoring.

Ontologies establish common vocabularies, definitions, and relations between (domain) concepts and thereby facilitate data integration and knowledge management. Food ontologies, such as FoodOn [11], provide a structured framework for organizing and representing food and food-related information, enabling data sharing and integration across different applications and domains. This information can be further linked to standardized models of physical quantities and measurement units (e.g., kilocalories) through ontologies such as QUDT [23], while other ontologies such as GoodRelations [21] offer standard ways representations for digital receipts. However, no existing ontology currently links digital receipts to food nutrition information, highlighting a critical gap in integrating dietary data.

In this paper, we introduce an ontology called *NutriLink*, which is designed to promote standardized machine-readable description of digital receipts from loyalty cards enriched with food nutrition information, from the point of purchase to the final stage of (nutrition) data analysis and recommendation. To quantitatively evaluate the nutritional quality of food purchases, this ontology also includes fine-grained product and basket Nutri-Score [26], a main front-of-pack nutritional labeling system in Europe (Please see more explanation in Section 2.1). NutriLink further links to established food ontologies, such as FoodOn, for enhanced data coverage and interoperability. In order to verify the utility of NutriLink, we demonstrate its usage in a fully automated dietary counseling system—this scenario and system also provide the foundation for the development of NutriLink, which is based on the Simplified Agile Methodology for Ontology Development (SAMOD) [43].

[1] https://www.tc260.org.cn/upload/2020-09-18/1600432872689070371.pdf The Article 8.6 mandates that basic personal information as well as personal health, physiological, educational, and occupational information need to be provided to third parties upon request of the data subject.

[2] https://world.openfoodfacts.org/

2. Related Work

In the following, we survey the context of NutriLink, including the food nutrition profiling systems, the provenance of food purchase and food composition data, and food and grocery purchase ontologies.

2.1. Nutri-Score and the British Food Standards Agency Nutrient Profiling System Dietary Index

Nutri-Score [26, 34] is a front-of-pack nutritional labeling system designed to provide a clear and intuitive overview of a food product's nutritional quality. It was first introduced in France, and then adopted by 6 other European countries [3] including Switzerland [54], where the NutriLink ontology was developed. Nutri-Score categorizes products on a color-coded scale from A (green, healthiest) to E (red, least healthy), allowing for quick visual assessment and practical decision-making assistance. The system is based on the Food Standards Agency Nutrient Profiling System (FSA-NPS), which evaluates food products using a scoring mechanism that considers 4 negative (energy; sugars; saturated fat; sodium) and 3 positive nutritional components (fiber; protein; percentages of fruits, vegetables, legumes, nuts, and specific oils (FVLNO) [22], or the percentages of fruits, vegetables, and legumes (FVL) in the most recent 2023 update [34]). The product FSA score can be obtained by combining the 7 dimensions and translated to the final Nutri-Score.

In December 2023, the Nutri-Score algorithm was updated to allow a better discrimination between products and closer alignment with food-based dietary guidelines [34]. Key changes include recategorizing some products, such as nuts and seeds; increasing maximum points for sugar (from 10 to 15) and salt (from 10 to 20); excluding oils and nuts from the FVL component (used to be FVLNO), and considering non-nutritive sweeteners as an unfavorable factor in beverages.

Beyond individual food products, a comprehensive nutritional quality metric – the British Food Standards Agency Nutrient Profiling System Dietary Index (FSA-NPS DI) [26] – is derived from the energy-weighted FSA scores of multiple products. This index simplifies implementation and minimizes debates around food categorization. Among several nutritional quality indicators of food purchases, the FSA-NPS DI has demonstrated stronger calibration and discrimination performance in classifying participants' consumption of nutrients and food categories [57].

2.2. Provenance of Food Purchase and Food Composition Data

Food purchase data has been attracting researchers' attention as it holds the potential to serve as an objective indicator of dietary patterns [18, 25, 57]. Objectively documented household food purchases, even partial food purchases, show moderate agreement with overall diet quality as measured through 24-h diet recalls [2, 42]. However, the manual collection and transcription of paper receipts are time-consuming and burdensome. Digital receipts from loyalty programs offer several advantages over paper receipts: Given a robust data pipeline to retrieve digital receipts in a machine-readable form, digital receipts require little manual effort to collect and analyze; the transcription of *digital* receipts is also less error-prone. In addition, digital receipts provide both up-to-date and historic shopping records, where the length of the shopping history depends on the shopper (*For how long has the shopper been a member of the loyalty program?*) and the retailer (*For how long is the data stored?*).

As discussed in the introduction, from a legislative perspective, the EU GDPR and similar regulations in other jurisdictions enable loyalty card users to access their digital receipts and transfer this information from data controllers, typically retailers. Thanks to these regulations, loyalty programs by grocery retailers have large user bases in many countries, which is relevant to enable a large part of the population to profit from diet monitoring and counseling services [12, 18, 25, 32, 35, 57]. This trend is particularly notable in Switzerland [57], where the the two largest supermarket chains, Migros and Coop, cover about

[3]https://www.santepubliquefrance.fr/en/nutri-score; accessed on February 27, 2025.

70% of the Swiss retail market [50]. The Migros loyalty card program covers about 80% of its total sales, while Coop does not disclose specific figures; however, research suggests similar rates [15].

Digital receipts typically do not contain product nutrition information. Nonetheless, they can be enriched leveraging information from food compositions databases (FCDs) that meet the following criteria [44, 58]: i) Be able to map ambiguous (abbreviated, e.g.,"FBud App.Brae", or broad, e.g., "Apple") item names on receipts to unique product identifiers; ii) Contain product size information, typically based on local stereotypes (e.g., a standard cucumber in France weighs 200 grams); iii) Contain product nutrition information, such as energy and nutrient content; iv) Contain food categorisation. To enable Nutri-Score calculation, it should additionally contain the FVLNO share [22], or the FVL share in the most recent 2023 update [34]. Extracting and calculating these percentages from ingredient lists requires significant manual effort.

2.3. Food and Grocery Shopping Ontologies

Researchers have been designing food ontologies to facilitate the representation and integration of food-related data. Boulos et al. [5] provide a detailed comparison of several food ontologies: FoodWiki [9], AGROVOC [8], Open Food Facts [40], the Food Product Ontology [29], and FOODS [49]. In addition, the FoodOn ontology [11] fills gaps in food product terminology and supports food traceability, including information such as animal and plant food sources, food categories and products, preservation processes, contact surfaces, and packaging. These ontologies have been designed to serve specific use cases and are hence with limitations. First, they focus on individual food products, not considering the combined nutritional quality of all consumed food products. Second, they are not suitable for integrating the full Nutri-Score framework, since – while e.g., Open Food Facts[2] does include information about products' final Nutri-Score values—they miss information about product Nutri-Score category and the product FVLNO or FVL share, which are required for computing product and basket FSA scores.

Apart from ontologies that focus on food products themselves, several ontologies could be leveraged to represent grocery items. One example is the GoodRelations ontology [21] for e-commerce. This ontology provides a standard set of terms and relationships to describe products, services, and businesses on the Web. GoodRelations is also integrated in the Open Food Facts ontology [40] to present core product data such as barcodes and brands [21].

Furthermore, schema.org (schema) provides several concepts that can be used to structure grocery purchases, such as `Product`, [4] `Offer`, [5] and `Order`. [6] Concepts from schema.org are commonly used in established ontologies. For instance, 5 of 315 schema.org classes and 27 GoodRelations classes cover the same entities. [7] One example is that `gr:ProductOrService` [8] is a subclass of `schema:Product` [4]. Besides, `gr:hasGTIN-14` is a sub property of `schema:productID`. [9] Similarly, the FoodOn ontology employs the `image` [10] concept from schema.org. Linking one ontology with schema.org concepts can be automatically achieved through its integration with ontologies that utilize concepts from schema.org.

None of the surveyed ontologies was found to be directly usable in our context, which includes the integration of digital receipts with FSA-based dietary recommendations. Nevertheless, inspired by these ontologies, we propose the NutriLink ontology and integrate it with several related established ontologies. The integration details are discussed in Section 3.2.

[4] https://schema.org/Product
[5] https://schema.org/Offer
[6] https://schema.org/Order
[7] http://wiki.goodrelations-vocabulary.org/GoodRelations_and_schema.org#overview
[8] http://purl.org/goodrelations/v1#ProductOrServiceModel
[9] http://schema.org/productID
[10] https://schema.org/image

3. The NutriLink Ontology

The NutriLink ontology was created following SAMOD [43], based on 3 key components: i) digital receipts from loyalty cards; ii) food nutrition information from an existing FCD; iii) aggregated information of products within a single basket. Our objective was to develop an ontology that effectively represents digital receipts enriched with food nutrition information, and integrates them with dietary recommendations.

3.1. Motivating Scenario and Competency Questions

Our motivating scenario aims at providing structured dietary recommendations to users based on their most recent food purchases. From this scenario, we derived a set of competency questions (CQs) for the NutriLink ontology: NutriLink should enable a system that collects information about purchased food items, where it should specifically know the amount of product purchased (CQ1). Based on such information, it should be able to aggregate nutrition information across baskets (CQ2), and provide the possibility to display the Nutri-Scores of shopped products and baskets to users (CQ3). To further enhance user feedback, the system should be able to compute nutrition and expense analyses, where bought food items are categorized into different food groups (CQ4). Finally, the system should be able to access necessary information for generating structured dietary recommendations (CQ5).

CQ1. What is the quantity of a specific product in a basket?
Digital receipts frequently provide limited information about item quantities and the specific quantity unit. Many items on digital receipts report a quantity of simply *1* without a unit. Hence, the specific product size and corresponding measurement unit may only be deduced when integrating with an FCD. Additionally, various measurement units could be used for nutrient measurements (e.g., *g* and *mg*) and product weights (e.g., *g*, *kg*, *ml*, and *l*). Standardization or conversion of these units to the same unit is crucial for further data analysis.

CQ2. What is the aggregated quantity and nutrition information across all products in a basket?
It should be possible to retrieve aggregated information across all items in a basket, including total price, total discount (if applicable), and basket nutritional metrics. Storing aggregated basket information eliminates repetitive calculations of static data, e.g., total price of a basket, and significantly simplifies subsequent data analysis. Nevertheless, the biggest challenge to aggregate basket-level information lies in maintaining a high-quality FCD as described in Sec. 2.2.

CQ3. What are the historic product- and basket-level Nutri-Scores in an individual's shopping history?
A clear and intuitive metric, such as the widely recognized front-of-pack label Nutri-Score [26], could effectively provide individuals with feedback on their overall shopping habits. In Switzerland, adopting Nutri-Score is particularly promising, since many consumers are already familiar with it. If calculated across multiple shopping baskets and displayed effectively [58], Nutri-Score could help users better understand their dietary patterns and make more informed food choices aligned with their nutrition goals. The basket-level Nutri-Score could be derived from the basket FSA-NPS DI (see Section 2.1), applying the FSA score thresholds in the Nutri-Score definition for letter conversions.

CQ4. What are the monthly energy and expense contributions of each food category for a shopper?
To enhance participants' understanding and engagement with provided dietary recommendations, the system should be able to inform them about the food categories that contribute most to their calorie intake and spending.

CQ5. What information about the most recent baskets is needed to generate structured dietary recommendations?

To provide relevant and robust dietary recommendations, we consider users' most recent food purchases and their nutritional quality. The nutritional quality of the recent food purchases is indicated by energy-weighted sub FSA scores (e.g., sugar score; there are 7 sub FSA scores as introduced in Section 2.1) of all food products in a basket. This energy-weighted approach is adopted by the definition of FSA-NPS DI [26] (see Section 2.1). Using household purchase data, our nutritional analysis is based on the assumption that each individual consumes food proportionally across all categories. For instance, if a person consumes 10% of the vegetables, this person also consumes 10% of other categories, such as sweets. Although simplified, this analysis approach allows for meaningful dietary insights derived from readily available shopping records. Through discussions with dietitians from our partner organization—Inselspital Bern from Switzerland—we have defined a structured recommendation format: "Increase/Reduce [Nutri-Score component] from [Food Category]" (e.g., "Reduce sugar from sweets"). More details about the structured dietary recommendations could be found in [58].

3.2. *Semantic Model*

The NutriLink ontology has been developed with the objective to answer these CQs while defining, describing, and integrating relevant attributes of digital receipts, food nutrition information, and dietary recommendations. After analyzing the *CQs* presented in Section 3.1, we decided to reuse the following ontologies:

- the QUDT ontology [11] to work with various quantity and unit standards and for unit conversion;
- the FOAF ontology [12] to represent users;
- the VAEM vocabulary [13] to represent names;
- the Dublin Core vocabulary [14] to represent images;

To expand NutriLink's coverage of food products globally, we integrate NutriLink with several established ontologies mentioned in Section 2.3. The concrete integration points, manually identified by the authors, focus on `nl:Product` and `nl:gtin`, and are outlined in Table 1. Integrating NutriLink with the FoodOn ontology provides a larger amount of food-related definitions, broadening the scope of NutriLink to non-consumer-oriented domains such as food production. Reciprocally, NutriLink's deeper coverage of consumer-oriented information, even beyond our specific CQs, supplements FoodOn's existing data. For instance, the NutriLink concept of `Allergen` [15] is considered in FoodOn only as a label through `food allergen labelling`. [16] Concretely, the `food product` class in FoodOn equals NutriLink's `Product` class. Regarding the NutriLink integration with GoodRelations, `nl:Product` is a subclass of `gr:ProductOrServiceModel`. Besides, `nl:gtin` equals `gr:hasGTIN-14`. Linking with GoodRelations enhances NutriLink's data interoperability, facilitating compatibility with existing web standards. On the other hand, NutriLink complements GoodRelations by offering more advanced features. For instance, the `qudt:Quantity` used in NutriLink has a richer and more detailed representation of quantities, including dimensions and types, compared to the `gr:QuantitativeValue` [17] in GoodRelations. Lastly, linking NutriLink with AGROVOC extends its coverage beyond food to agriculture-related domains, providing multilingual support. The `agrovoc:products` is an instance of `nl:Product`. Through the integration of NutriLink with GoodRelations and FoodOn, NutriLink is automatically integrated to relevant concepts on schema.org employed by GoodRelations and FoodOn, as introduced in Section 2.3.

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[11]https://github.com/qudt/qudt-public-repo/blob/c3fdf5f95cd2228714eb0a535903dc7f82a18b4c/src/main/rdf/schema/SCHEMA_QUDT.ttl
[12]http://purl.org/spar/foaf
[13]http://www.linkedmodel.org/1.2/schema/vaem
[14]http://purl.org/dc/dcmitype/Image
[15]https://github.com/Interactions-HSG/NutriLink/blob/main/NutriLink.owl#L1085
[16]http://purl.obolibrary.org/obo/FOODON_03510215
[17]http://purl.org/goodrelations/v1#QuantitativeValue

The OWL formalization of our model, along with all relevant queries (in SPARQL) is openly available on our Github repository. [18] In the following, we present parts of NutriLink by introducing how it implements the *CQs* as proposed in Section 3.1 in the context of a fully automated dietary counseling system based on digital receipts [58].

Table 1
Description of several established ontologies and schema.org, and the integration points between them and NutriLink (nl)

Ontology	Description	Integration point(s)
FoodOn [11]	FoodOn contains vocabulary for naming food materials and their anatomical and taxonomic origins, from raw harvested food to processed food products, for humans and domesticated animals.	`foodon:FoodProduct` is a subclass of `nl:Product`
GoodRelations (gr) [21]	GoodRelations is a lightweight ontology for exchanging e-commerce information, namely data about products, offers, points of sale, prices, terms and conditions, on the Web.	- `nl:Product` is a subclass of `gr:ProductOrServiceModel` - `nl:gtin` equals `gr:hasGTIN-14`
AGROVOC [8]	AGROVOC is a relevant Linked Open Data set about agriculture available for public use and facilitates access and visibility of data across domains and languages.	`agrovoc:products` is an instance of `nl:Product`
Schema.org	Schema.org is a collaborative, community activity with a mission to create, maintain, and promote schemas for structured data on the Internet, on web pages, in email messages, and beyond.	The integration of NutriLink with Schema.org concepts is done through its integration with GoodRelations and FoodOn, which employ concepts from schema.org.

3.2.1. *Overview of the NutriLink Ontology*

To give an overview of the NutriLink ontology and its semantic coverage, we provide here its most relevant concepts (omitting the namespace) along with brief comments if the concept name is not self-explanatory: `Abstention` (of a user from a product ingredient), `Allergen`, `Basket`, `BasketAggInfo` (i.e., aggregated information about a basket such as total price), `DietCoachMajorCategory` (i.e., major food category such as *Processed food*), `DietCoachMinorCategory` (i.e., minor food category such as *Salty snacks*), `Dietitian`, `Item` (items on receipts, identified by item names), `MarketRegion` (to specify the geographical availability of a product), `NutriScoreCategory`, `NutritionInformation` with the three subclasses `Nutrient`, `NutriScore`, and `OfComDetail` (i.e., the detailed FSA scores of a product); furthermore `Office` (exact supermarket store), `Product` (products on FCD, identified by GTINs), `Retailer`, and `User`.

`Basket` is the fundamental class for describing digital receipts. We define the `Basket` class to represent the collection of `Item` instances within a specific basket or shopping session, where a session is considered as unique based on a hash of the checkout timestamp, user identifier, and retailer outlet identifier (i.e., `Office`). A successful match of an instance of `Item` class to an instance of the `Product` class links receipts to nutrition information. A `Product` instance is typically linked to multiple instances of the `NutritionInformation` class, which contains 3 subclasses: `Nutrient`, `NutriScore`, and `OfComDetail`. The `Nutrient` class describes the nutrient content per 100 g of the product for a specific nutrient. Based on this information and following the FSA-NPS definition, the detailed FSA scores of the product are described in the class `OfComDetail`; the `NutriScore` class is used to represent the Nutri-Score of each product and basket.

[18] https://github.com/Interactions-HSG/NutriLink

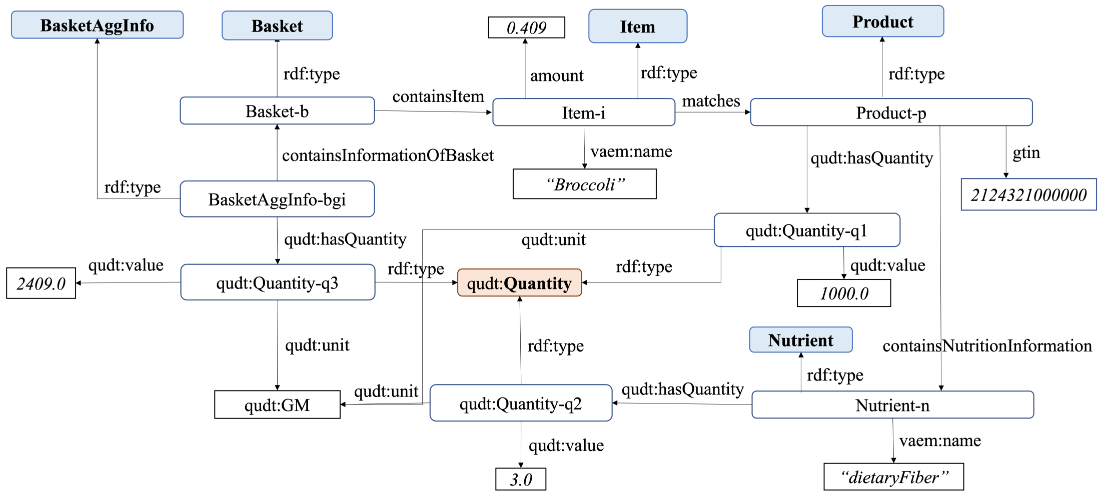

Figure 1. Semantic description of an *Item* instance Broccoli using NutriLink.

To provide an overview about baskets, NutriLink contains the `BasketAggInfo` class, which stores the static aggregated information about instances in the `Basket` class. Information that the `BasketAggInfo` class provides includes total expense, total discount and total nutrition information (e.g., nutrient content, average FSA score and Nutri-Score) if any food products with nutrition information within baskets have been identified.

Fig. 1 depicts how the classes `Basket`, `Item`, `Product`, `Nutrient`, `qudt:Quantity`, and `BasketAggInfo` are connected in an example item labeled *Broccoli* and associated with a product identified by the GTIN *2124321000000*. For more details about the ontology, please refer to our GitHub repository.[18]

3.2.2. *Addressing CQs Using NutriLink Ontology*

In the following, we discuss how the NutriLink ontology can be used to answer our CQs.

Accessing Quantities of Products in a Basket (CQ1) In our system, we used `qudt:Quantity` to represent quantities related to classes `Product`, `Nutrient` and `BasketAggInfo`, and to allow for consistent presentation and handling of quantity values across the ontology. We described the quantities of instances of `Item` using `amount`, because no quantity unit was provided for items. Answering CQ1, Listing 1 shows a SPARQL query that retrieves the item quantity and the corresponding product quantity using QUDT.

Accessing Aggregated Basket Information (CQ2) To address *CQ2*, the classes `Basket`, `Item`, `Product`, `Nutrient`, `OfComDetail` are needed to describe specific information from individual baskets. These information include item names, item quantities, item prices, matched product quantity values and units, matched product nutrient quantities and units per 100 g product, and matched product FSA score details. The basket-level Nutri-Score is derived from the basket's FSA-NPS DI by averaging the FSA scores of all products in the basket, with each product's energy contribution weighted accordingly, as introduced in Section 2.1. Not all aggregated basket information is always needed. Therefore, we provide a SPARQL query retrieving basket-level aggregated Nutri-Scores from recent baskets in our GitHub repository[19] to as an example answer for CQ2.

Accessing Nutri-Scores from Shopping History (CQ3) To address *CQ3*, the classes `Basket`, `Item`, `Product`, `BasketAggInfo`, and `NutriScore` are needed to describe basket timestamps, basket Nutri-Scores, item names, item quantity, and product Nutri-Scores. The corresponding SPARQL query used to retrieve these information from knowledge base can be found in our GitHub repository. [20]

[19]https://github.com/Interactions-HSG/NutriLink/blob/main/sparqlQueries/CQ2.rq
[20]https://github.com/Interactions-HSG/NutriLink/blob/main/sparqlQueries/CQ3.rq

```
PREFIX nl: <http://purl.org/nutrilink#>
PREFIX vaem: <http://www.linkedmodel.org/schema/vaem#>
PREFIX qudt: <http://qudt.org/schema/qudt#>

select distinct ?gtin ?itemQuantity ?prodSize ?prodSizeUnit
where{
    ?item vaem:name "Broccoli".
    ?item nl:amount ?itemQuantity.

    optional {
        # Find the Product that matches the Item
        ?item nl:matches ?product.
        ?product nl:gtin ?gtin.
        ?productQuantity qudt:value ?prodSize.
        ?productQuantity qudt:unit ?prodSizeUnit.
    }
}
```

Listing 1: Using QUDT to present the product quantity of an item named Broccoli.

Accessing Monthly Nutrition and Expense Analysis (CQ4) To answer *CQ4*, energy content and prices of items that were purchased in a given month need to be retrieved for nutrition and expense analysis. The detailed SPARQL query can be found in our GitHub repository. [21]

Access Dietary Recommendations (CQ5) In the fully automated dietary counseling system FoodCoach [58], we generate structured dietary recommendations based on the product nutrition information from the most recent 10 baskets. To achieve this, we retrieve various details from the knowledge base, including item amount, product quantity values and units, corresponding food categories, product nutrient/energy content, product FSA scores. The SPARQL queries that retrieve this information can be found on our repository. [22,23] In the future, we plan to collaborate with our hospital partners, enabling registered dietitians to give structured dietary recommendations based on food purchases recorded on loyalty cards to study participants or patients. We will provide dietitians with nutrition information of baskets similar to what we retrieve for automated recommendation according to NutriLink. To access dietary recommendations (e.g., *Reduce sodium from cheese products*) through NutriLink and in the format that we defined with our hospital partner, instances of `Recommendation` are linked to food categories (i.e., `DietCoachMinorCategory`, such as cheese products) and to nutrients (i.e., `Nutrient`, such as sodium). A recommendation is furthermore associated with a boolean flag through the property `increaseContent` that signifies whether the user should increase (or decrease) the consumption of the targeted nutrient in products of the targeted category. Recommendations carry, as further properties, a `recommendationPriority` (integer) and a human-readable explanation (string), and are associated with an instance of class `User` and a timestamp; furthermore, to permit tracking the origin of a recommendation, they are linked to an instance of class `Dietitian`, where this might be a person or a handle of an automated system that created the recommendation.

4. Case Study: Fully Automated Dietary Counseling through NutriLink

The CQs that we introduced in this paper (see Section 3.1) and those formed the basis of the NutriLink ontology originated from an interdisciplinary research project FoodCoach [58], a fully automated dietary counseling system based on digital receipts. This system has been developed together with our hospital partners and has been deployed and successfully pilot-tested with 76 users, including 15 test users.

[21] https://github.com/Interactions-HSG/NutriLink/blob/main/sparqlQueries/CQ4.rq
[22] https://github.com/Interactions-HSG/NutriLink/blob/main/sparqlQueries/CQ5_a.rq
[23] https://github.com/Interactions-HSG/NutriLink/blob/main/sparqlQueries/CQ5_b.rq

Our system retrieves digital receipts via shoppers' loyalty cards from Migros and Coop in Switzerland. The digital receipt integration is facilitated by a third-party service that manages user consent and digital receipt extraction from the retailers. The transferred receipt data contains information about the bought article names, quantities, prices, discounts, receipt timestamps, store names, and store location (latitude and longitude); furthermore, we received metadata including a user identifier and consent record. Post-receipt, we remove the store names and store location and reduced the precision of the receipt timestamp from milliseconds to days to minimize the consequences of a possible data leak in our graph database, since this effectively anonymizes the receipts data. The sanitized receipt data is then inserted – according to the NutriLink ontology – into a GraphDB[24] instance that runs on premises in our institute.

The study team has been maintaining an FCD that meets the requirements in Section 2.2. It contains more than 50,000 products from 126 categories [16]. The FCD is based on Trustbox Switzerland [19], with expanded product coverage through manual additions. Data quality is improved via automated validation (e.g., the sum of all nutrients should not surpass 100 g per 100 g product) and manual verification. Receipt items are matched to FCD products using automated methods (e.g., regular expressions) and manual verification. Currently, the FCD only employs the older Nutri-Score algorithm for Nutri-Score calculation. We are working on integrating the most recent Nutri-Score algorithm to the FCD.

The FCD links inserted `Item` instances to instances of the `Product` class. If an item is successfully matched, the FCD returns the following product attributes: GTIN; product name (in several languages); product size and unit; energy content; content of nutrients (total carbohydrates; sugars; total fats; saturated fats; proteins; fiber; salt; sodium); product FVLNO share; product image(s); product ingredients (as a string); allergens (NutriLink supports 14 different allergens); minor food category; major food category; Nutri-Score category; Nutri-Score; and FSA score details. This information, which is then available via our GraphDB instance and structured according to the NutriLink ontology, forms the basis of FoodCoach.

Our system can be used by users whose data has successfully been integrated through the mobile-first Web application FoodCoach. [25] Following the Backend for Frontend (BFF) pattern and similar to the method proposed in [33], this application – whose features correspond to the introduced CQs – communicates with the GraphDB indirectly: The application triggers the SPARQL queries that correspond to its currently relevant CQs through a back end and renders the results in a format that makes them easily accessible to users. The resulting views are shown in Fig. 2:

- Corresponding to CQ2, the view *Nutri-Scores of Baskets* presents the Nutri-Scores of the seven most recent baskets of a user. The view additionally shows a comparison of the overall weighed Nutri-Score of these baskets of the active user to the scores achieved by all other users of the system over the previous four weeks.
- Corresponding to CQ3, the view *Shopping History* displays the user's purchase history, product Nutri-Scores, and aggregated basket Nutri-Scores.
- Corresponding to CQ4, the views *Nutrition Analysis* and *Spending Analysis* visualize energy and expense contributions across seven food categories (protein foods; vegetables; fruits; processed food; grains, potatoes and legumes; beverages; and oils, fats, sauces, nuts and seeds).
- Corresponding to CQ5, the view *Automatic Recommendations* provides dietary recommendations along with explanations. It also shows alternative healthier products in the same food category, based on the previous ten baskets of the user that contain identified food products. The currently deployed version of our system fetches raw nutrition information across baskets and computes the recommendations locally.
- All shown views depend on answering CQ1 to retrieve information about *absolute* or *relative* product quantities.

[24] https://www.ontotext.com/products/graphdb/
[25] www.foodcoa.ch

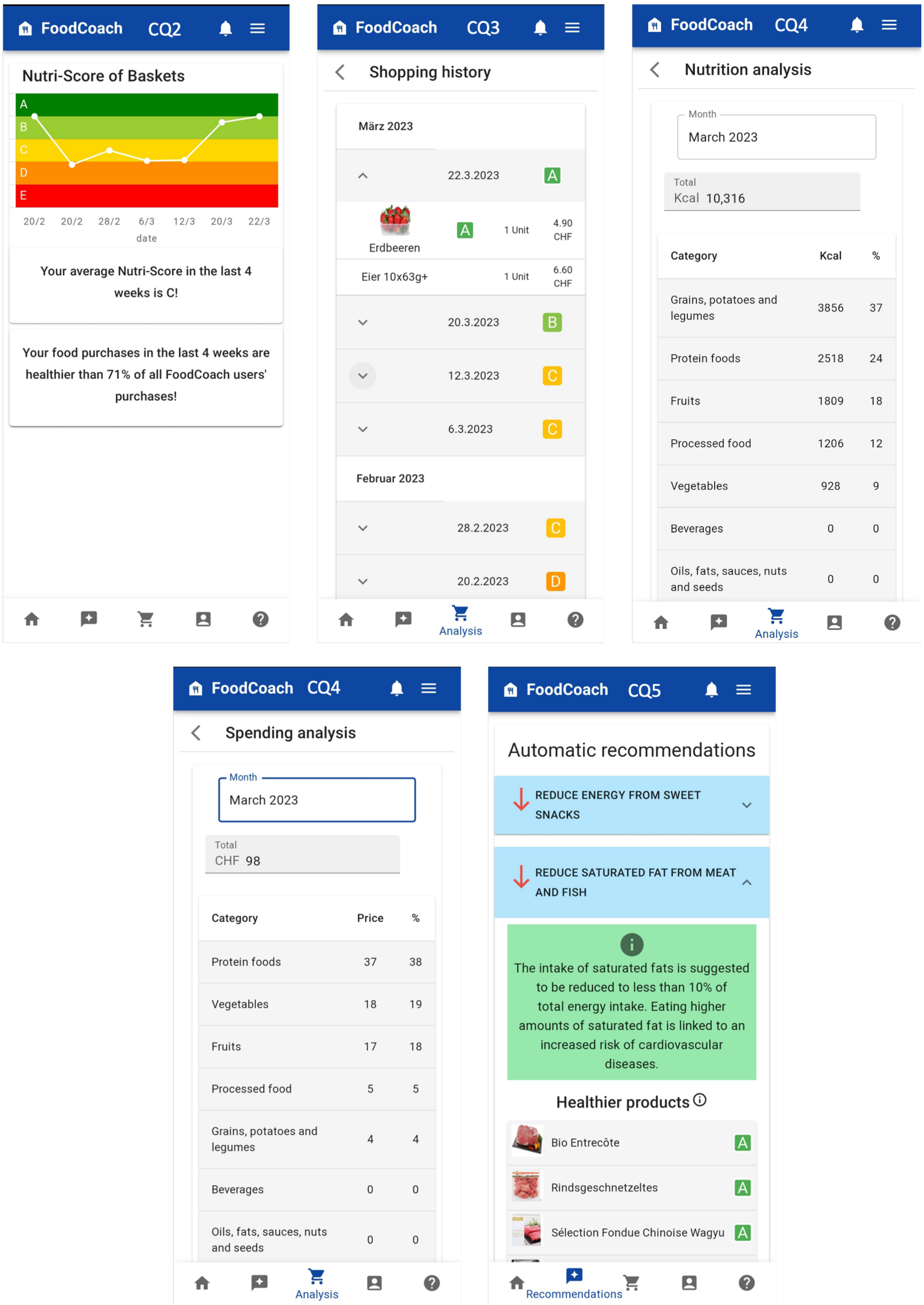

Figure 2. Visualization of data that conforms to the NutriLink ontology in the mobile-first Web application FoodCoach[58]. Each view corresponds to one competency question introduced in Section 3.1.

5. Limitations and Future Work

The NutriLink ontology has several limitations. First and most importantly, the ontology was created mainly based on (food and non-food) products on digital receipts from two major loyalty card systems in Switzerland. The applicability of our ontology has hence not been verified for products from paper receipts, farmers' markets, restaurant meals, or home-made dishes. We argue that NutriLink should still be applicable to these products, since the data that our CQs and queries depend on is standard retail data (amount, price, weight, etc.) and nutrition information (energy in KJ, sugar in g etc). The main challenge in extending NutriLink to additional products is retrieving this information in digital formats. Potential solutions include a combination of digital tools and manual data correction. To digitalize paper receipts, optical character recognition (OCR) combined with transformer-based models for layout understanding provides potential solutions [1, 45]. However, this manual scanning approach is burdensome and error-prone, due to potential duplicate or missing scans. For restaurant meals, obtaining accurate nutritional information is challenging despite EU Regulation No. 1169/2011 requiring its provision. One solution is to scrape nutritional data from restaurant websites where available or estimate average values for local meals. Similarly, home-made meals could be approximated using local averages. For farmers' market products, national food composition databases, such as the Swiss Food Composition Database, [26] could provide nutritional data, while product sizes and prices may need to be manually entered based on specific use cases.

Second, the NutriLink ontology only models the nutrition information of raw products, neglecting practical factors that could heavily affect the people's nutritional intake, such as food preparation and food waste. This limitation could be mitigated by integrating people's eating/cooking behavior captured via questionnaires, at the cost of requiring more efforts from users.

Third, receipts themselves can occasionally be unreliable, e.g., because of product returns. Although food product returns rates are in general low (e.g., only 1-3.9% of food products sold online were returned in Switzerland in 2022 [59]), we can extend NutriLink to cover this aspect in the future.

Fourth, as NutriLink has been geared towards *dietary* analysis and the provisioning of dietary recommendations, overlooking other relevant aspects of food products. For instance, NutriLink lacks sustainability characteristics of a food product. Environmental aspects like greenhouse gas emissions could be integrated into `nl:Product` using databases such as the World Food LCA database [27] [44], or retailer websites, when available. Similarly, social aspects like Fair Trade certification [28] could be incorporated when suitable standards are identified.

Lastly, the adoption of NutriLink faces social and organizational barriers, including varying digital literacy among researchers and practitioners and complex institutional decision-making processes.

As next steps, we plan to expand NutriLink to include more food products , especially from beyond supermarkets. We will also update the ontology to reflect the most recent Nutri-Score update as discussed in Section 2.1 and to incorporate the sustainability aspects. More research in the user experience and user interface aspects should also be conducted for broader adoption and applicability of NutriLink. Additionally, we will explore potential collaborations with international partners to assess NutriLink's applicability in other regions and support related research, such as the work of the International Network for Food and Obesity/Non-communicable Diseases Research, Monitoring, and Action Support (INFORMAS) [53], as opportunities emerge.

6. Conclusions

We presented the NutriLink ontology that links digital receipts to food nutrition information and dietary recommendations. Compared to existing food ontogies, NutriLink additionally covers fine-grained

[26]https://valeursnutritives.ch/en/
[27]https://simapro.com/products/quantis-world-food-lca-database/
[28]https://www.fairtradecertified.org/

details of food products, which is relevant for Nutri-Score computation. The integration of NutriLink with FoodOn, GoodRelations, AGROVOC, and schema.org concepts significantly enhance its coverage, data interoperability, and multilingual support globally. We verified the utility of the ontology by implementing it in a fully automated dietary counseling system based that has been used by 76 users. We propose that NutriLink can allow researchers to better integrate and analyze food-related data, advancing digital monitoring and intervention in nutrition and beyond. Additionally, it can contribute to the development of evidence-based policies and interventions to promote healthy food purchasing, hence helping combat NCDs.

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