Ontological Framework for representation of Tractable Flavor: Food Phenotype, Sensation, Perception.

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Abstract. Among all sensory sciences, flavor remains a wicked problem. Sight, sound, and touch have all been digitized, and vast resources exist around their computation.. While the biological basis for food consumption is primarily to nourish bodily functions, it fulfills a greater second function of sensory pleasure. Flavor, and the pleasure it engenders, is the primary driver of food choice. Moving toward a semantic web of food that enables personalization of food and flavor experiences requires an interoperable ontological model of flavor. This paper proposes a framework of several ontologies to model a comprehensive view of flavor, by partitioning it into three interoperable matrices of interacting variables: objective characteristics of food, subjective sensory experience, and interpretive communication of that experience. The objective matrix details the properties and behaviour of food molecules. The subjective matrix represents the multilayered and highly individualised consumption and sensory perception variables. The interpretative layer deals with the communication and language used to describe the food experience. Together these three matrices represent an initial ontological model for the flavor and sensory experience portion of the emerging semantic web of food.

I. Introduction

In 1973, two social scientists, Horst Rittel and Melvin Webber defined a class of problems they called “wicked problems”.[1] Wicked problems are messy, ill-defined, more complex than we fully grasp, and open to multiple interpretations based on one’s point of view. [2] Flavor among all sensory neurosciences remains a wicked problem. While many researchers have proposed methods for digital replication of specific tastes and aromas [3], to date there exists no semantic or ontological models for operating over food flavor and the sensory experience.

Selection of food for nourishment in animals is an evolutionary process, influenced by habitat and ecological conditions, whereby recognition of tastants and especially odorants are associated with (dis)pleasurable eating and post-prandial experiences, and highly influence repulsion/desire for future consumption. Learned consequences of ingested foods continue to influence food choices in humans, ubiquitously known as the multi-modal sensation of flavor. [4–6] Challenges for designing computational flavor systems are effectively highlighted by comparison to more developed computational neuroscience systems of vision and sound, where scientific research and technology successfully mapped physical properties of stimuli to their perceptual characteristics. We argue that these systems were comparatively easy to digitize due to the continuous nature of their data. In vision, wavelength translates into a RGB color model; in audition, frequency and wavelength translates into amplitude/pitch model. [3] This information digitisation provides unambiguous identification of colour and sound, without influence of perception or hedonic response. We utilize an analogous approach to solving the wicked flavor problem, albeit the dimensionality of flavor is orders of magnitude greater than for sound or colour, and requires multiple layers (matrices) of variable separation. The reference to “matrix” in this paper is not the algebraic matrix, but a complex state of interacting variables. The ontology-based model has 3 principle matrices: Objective characteristics of food (Food Phenotype), Subjective Sensory Experience, and Interpretive Communication of the perceived experience. These broadly correspond to the knowledge domains of Food Science, Sensory/Neurophysiology, and Anthropology/Psychology/Linguistics respectively.

II. Tripartite flavor Model

The model in Figure 1 shows the three matrices. The first matrix enclosed by a curve dashed line represents the Food Phenotype Matrix, unbiased by individual response. The second matrix, enclosed in the human body boundary, represents the sensory capture and modulating factors in decoding the ingested food. The third layer still partly enclosed in the human boundary is the interpretation of the experience which is finally communicated.

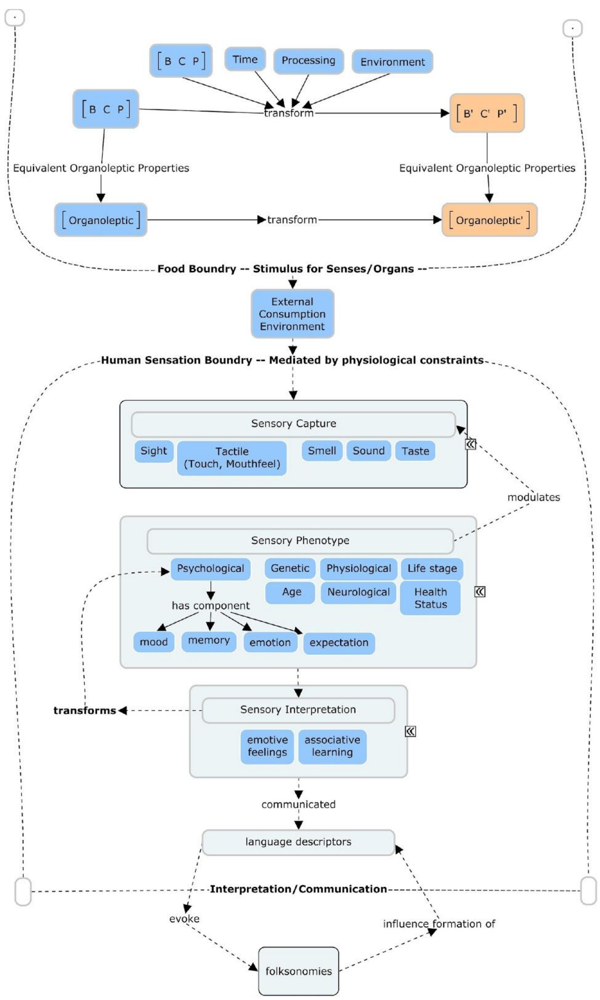

Fig. 1. Tripartite flavor Model.
Boundary lines separate three matrices; Objective characteristics of food (Food Phenotype), Subjective Sensory Experience, and Interpretive Communication of the perceived experience, explained in section II A,B,C resp.

A Objective Matrix

Food is classified into components and properties shown in Figure 2. Biological components include living cells like bacteria and morphological features of the food, like germ, bran and endosperm in a grain or the milk fat globule membrane in milk which is a structure composed primarily of lipids and proteins that surrounds milk fat suspended in an aqueous medium which includes other soluble and insoluble compounds. Chemical components are all atoms/compounds in foods classified by molecular structure. Biological properties are the bioactivity roles, Chemical properties characterize the reactability and aroma. Physical properties include Rheological, Morphological, Surface, Acoustic, Volumetric, Reflective/Refractive properties to name a few. Within the objective matrix, the biological, chemical and physical properties are expressed by three vectors [B,C,P]. This notation connotes the state of a food at a given point in the timeline of its transformation.

"Organoleptic properties are the characteristics of the Phenotypic classes detectable by electrical, mechanical, chemical, and temperature bio- mechanisms and felt as the sensation of touch, sight, smell, taste, sound, inflammation, and lacrimation. Hence the Organoleptic Ontology has relevance to the consumption of food and is at the boundary of the objective and sensory matrix." [7] It is expressed by the variable [Organoleptic] and is associated with a given [B,C,P].

The Objective matrix illustrates the transformation of a given [B,C,P] into another [B',C',P'] as a function of all or any of the variables ;an added ingredient represented by [B,C,P], the passage of time for example in the ripening or rotting of a fruit, a food altering process, and variables for the environment the food is in for example environmental conditions at high altitude or at sea level on the ground.

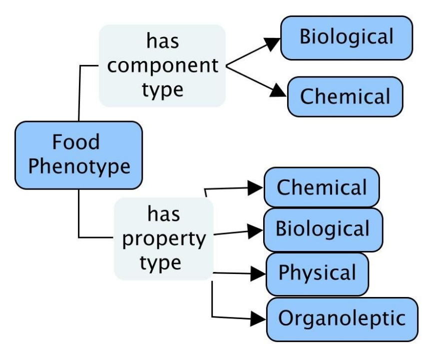

Fig. 2. Food Phenotype Ontology model

This [B,C,P] representation is in early stages and known caveats should be mentioned explicitly to avoid any confusion or misrepresentation of present capabilities.While it has been stated earlier that the Matrix is not the algebraic matrix, it should be mentioned that the formulaic representation in its current form is highly simplified and will evolve to several algorithms connecting properties, their transformational variables and phenotypic outcomes.

An ongoing project to characterise dough is a use case for this model and a means to vet and develop it. The project proposes to define the [B,C,P] model for flour and added ingredients like salt, water, yeast, quantify the transformational energy of force and time and environmental conditions of temperature and humidity , and define the [B,C,P] model of the resulting dough.

B Sensory Matrix

The sensory apparatus and neural processing is a highly-nuanced combination of psychological and physiological factors shown in the second layer of the matrix framework. The olfactory apparatus is approximately 400 odorant receptors, but each individual has a unique set of genetic variations [3]. Factors like ancestry, age, and gender accounted for over 70% of the explainable variance for some odors (guaiacol, diacetyl, and nonyl aldehyde) and less than half of the explainable variance for others[8]. The taste papillae in the tongue vary in density across individuals and throughout the life span.[9, 10]. A comparative study of groups, with varying higher taste bud densities reported these perceptions; sucrose (196%), NaCl (135%) ,PROP (142%), Citric acid (118%) and quinine HCl (110%) than the lower density group [11]. Anosmia and hyposmia, the inability or decreased ability to smell, is estimated to afflict 3–20% of the population and is linked to old age,chronic sinonasal diseases, severe head trauma, upper respiratory infections, or neurodegenerative diseases [12].

On the psychological front, stress causes changes in neuroendocrine balance (high cortisol and insulin) thus impeding the more reflective cognitive control over eating that is distinct to humans leading to non-homeostatic eating patterns. Associative learning acquired from repeated exposure to a specific organoleptic stimulus drives changes to the peripheral sensory organs themselves [13]. Emotive responses add a further variable in the interpretative process.Moods and emotions ranging from neuroticism, to conscientiousness influence eating styles and food choices [14].

The Sensory matrix has three distinct interacting components. The peripheral sensory organs relevant to organoleptic stimulus are modulated by the Sensory Phenotype variables which include aforementioned physiological, psychological and neurological factors. These Sensory Phenotypes are in turn modulated by the Sensory Interpretation layer which includes emotive responses and associative learning.

C Interpretative Matrix

Across human existence, social constructionism has given rise to varied informal vocabularies across socio-cultural demographics. These folksonomies represent collections of words utilized by humans to model their varied experience arising from their social and cognitive processes [15]. Fenko et al describes expressions divisible into three groups: sensory descriptors (hard, red, noisy); symbolic descriptors (interesting, expensive, modern); and affective descriptors (pleasant, beautiful) [16]. More recently, social constructionism popularised “freshness”. Judgments of freshness vary based on colour and smell cues and generally have little to do with the temporal aspect of “freshness” [17]. Ontological modelling of Food Phenotypes, and especially their Organoleptic Descriptors, remains challenging due to the fact that these folksonomies have percolated through layers of sensation and perception whose context is culturally dependent. This effort to distinguish interpretation from content can be appreciated in the context of the constantly growing world wide web where user-tag based folksonomies are used to catalog web content and drive personalised search strategies. [18]

III Ontological Representation

The logical matrix flavor model connects the inherent properties of food to its sensory perception. The representation maps to focussed disciplines that have remained isolated: objective characterisation of food phenotype, sensory analysis and consumer perception. The development of high throughput technologies and emerging AI applications presages the need for an integrated ontological framework. This trend bears similarity to the events and developments in molecular biology that lead to the OBO Foundry, being instrumental to the success of the Gene Ontology. [19] In alignment with objectives of OBO to foster and organise ontological development, and the foundational Continuant-Occurrent architecture, the matrix representation is formalised into a modular ontological system. It is important to point out that the future work is to develop the Phenotype and Interpretative ontologies.

CONTINUANT			OCCURRENT
INDEPENDENT		DEPENDENT	
Environmental Matrix Surrounding Foods	Food Chemical Components	Food Chemical Properties	**Food Transformation Process**
	Food Biological Components	Food Biological Properties	Food Biological Transformation Process Food Chemical Transformation Process
		Food Physical Properties	Food Thermodynamic Transformation Process
		Organoleptic Properties	Ingredient Addition Process
Environmental Matrix Surrounding Humans	Human Sensory Apparati	Human Sensory Phenotype Qualities/ Traits	**Sensory Experience Process** Sensation Process (neurological) Sensory Emotive/Learning Process Sensory Interpretation/ Communication Process

4 CONCLUSION

The digital model for flavor is an important part of the semantic web of food. The suggested design enables capabilities like the prediction of flavor outcomes resulting from specific processes and ingredient combinations, personalization of experiences, and integration of flavor variables with those related to health outcomes and sustainability metrics to promote behaviour change without sacrificing desirability of foods. Framing the flavor model in modular sections considers the (future) role of measurements to support reasoning and decision making in any food processing sequence toward a desired phenotypic outcome. The Food Phenotype model can also be applied towards quality/grading standards of commodities; for example, characterizing and differentiating products like tea, bread, and cocoa based on ingredients and processing methods--thus establishing bases for price premium via quality standards, thereby giving recognition to artisanal/speciality segment products.

The proliferation of applications for computational flavour may cause unruly ontology creation and development, and this suggested architecture could guide in creating ontologies of varying granularities; top level ontologies and specialised ontologies that link and harmonise consistently and efficiently. ChEBI is not intended for culinary application, since the 'has role' relationship which links chemical entities to their roles and 'has part' which links composite entities [20] has some incomplete or incorrect coverage of culinary data. For example Molasses "has part" glucose, "has part" fructose, and "has part" sucrose and "has role" flavouring agent is incomplete since the constituents are not quantified and the role of "flavouring agent" is too broad and hence non informative.. Another limitation is the lack of a causal relationship between the structural properties and role. The specific chemical structural property linked to the the role of emulsifier is essential from a culinary perspective for the next step of defining reactions. FOODON must be recognised as an upper level ontology that organises food products from the LanguaL-indexed SIREN database into subclasses like food safety, food processing and agricultural and animal husbandry practices. However the subclasses do not explain the specific dynamics and reactions of the food process, which is better left to specialised ontologies.

In conclusion this architecture disambiguates objective properties of food from its subjective experience while also suggesting an architecture to organise this vast information.

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