Data Edibilization: Representing Data with Food

Yun Wang
The Hong Kong University of Science and Technology
Clear Water Bay, HK
ywangch@cse.ust.hk

Qiong Luo
The Hong Kong University of Science and Technology
Clear Water Bay, HK
luo@cse.ust.hk

Xiaojuan Ma
The Hong Kong University of Science and Technology
Clear Water Bay, HK
mxj@cse.ust.hk

Huamin Qu
The Hong Kong University of Science and Technology
Clear Water Bay, HK
huamin@cse.ust.hk

CHI'16 Extended Abstracts, May 07-12, 2016, San Jose, CA, USA
 ISBN 978-1-4503-4082-3/16/05$15.00.
DOI: http://dx.doi.org/10.1145/2851581.2892570

Abstract
Data communication is critical in data science. We propose data edibilization, i.e., encoding data with edible materials, as a novel approach to leverage multiple sensory channels to convey data stories. We conduct a preliminary data tasting workshop to explore how users interact with and interpret data edibilization. Based on the participants' feedback, we summarize the advantages of edibilization in terms of attractiveness, richness, memorability, affectiveness, and sociability. We also identify several challenges with data edibilization. We discuss possible pragmatic processes, enabling technologies, and potential research opportunities to provide insights into the design space of data edibilization and its practicality.

Author Keywords
Data edibilization; data cuisine; information visualization; physicalization.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
Data communication is an essential component in data science. By articulating findings and insights from data, the values of data can be better realized. Researchers and

Figure 1: A 3D-printed pastry shell embedded with yeast, mushrooms, edible soil, and sprouts, © Chloé Rutzerveld [55].

practitioners have been experimenting with different ways to tell stories about data [15]. Visualization is the most commonly used technique. Vision is a primary channel for humans to obtain information [21]. A concisely and meticulously designed visualization system is able to provide people with an instant understanding of the characteristics of the data [31, 40]. The introduction of data sonification [34] and physicalization [27] demonstrates the possibility and potential of involving the sense of hearing and touching in analysis and exploration of data.

The design space of data representation can be further expanded to include smell and taste in a compatible/harmonious manner, making the data representation even more vivid and memorable [52]. For example, Figure 1 shows a 3D-printed biscuit with edible mushrooms growing in it. If this biscuit is served as a snack at a workplace, people can track their working hours, the temperature, and humidity in the office by monitoring the growth of the mushroom. Employees can compare and taste mushrooms displaying the working conditions at the end of the day. In addition, choosing seasonal, local ingredients will add cultural/regional flavor to the whole experience.

In this paper, we define the process or an instance of communicating data using attributes of edible materials, such as appearance, texture, sound, taste, and smell of foods and drinks as *Data Edibilization*. The definition shows that data edibilization is related to but extends beyond food production. When we cook food, we try to make the dishes enjoyable and nutritious. Similarly, when we "cook" data, we leverage the rich sensory experiences and the positive psychological effects that food entails to tell an interesting story with data, instead of merely showing numbers.

Emerging technologies have made the process of transforming data to an edible presentation easier and more widely accessible. For example, *IBM Chef Watson* uses machine learning techniques to automatically generate new recipes of flavorful dishes that suit customers' needs and tastes [10]. Smart cooking appliances and 3D food printers can automate the food production process to a great extent. They are becoming more affordable for ordinary households [59]. Attempts to use food as a data communication medium have been made [2, 28, 29]. However, no systematic research on data edibilization has been conducted, to the best of our knowledge.

We summarize the contributions of this paper as follows:
(1) We define data edibilization as a means of presenting data, and conduct a preliminary study in the form of a Data Tasting Workshop to gain an in-depth understanding of the advantages and challenges of data edibilization.
(2) We examine the different components, namely, anticipation, production, and consumption, that constitute an integrated experience of data edibilization.
(3) We propose three design processes, namely, food-based, data-driven, and hybrid approach to construct data edibilization.
(4) We compare data edibilization with existing data representation methods, identify possible research opportunities, and sketch a research agenda for the Human-Computer Interaction community.

Characteristics of Data Edibilization

Data edibilization adds another layer of complexity. Designers need to consider the data-ingredient fit to create a coherent experience. There have been some empirical exploration of data edibilization, and we divide the outcomes into two categories.

The **first style** of edibilization reserves the look of an ordinary dish but with data encoded. For example, six fruit-

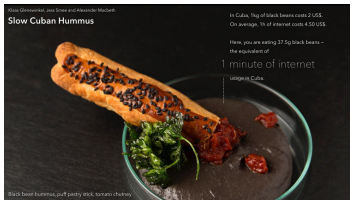

Figure 2: The designer of *Slow Cuban Hummus* used the cost of black beans to indicate the cost of internet usage [28], © Data Cuisine. (Photo by Uli Holz)

Figure 3: In *Taste of Migration*, nationalities are represented by the typical food of each country [28], © Data Cuisine.

cakes (a.k.a., Christmas stollen) are used to represent a person's Christmas spending through the amount of nuts and dried tropical mixes in the dessert. It is rather easy to perceive the individual differences between each fruitcake visually [1]. Another example in Figure 2 is to show the cost of one minute of Internet usage in Cuba, compared with the cost of black beans. By showing 37.5 g black beans that cost the equivalent of one minute of Internet, people can easily connect intangible Internet usage with tangible food.

The **second style** of edibilization simply reconstructs common data visualizations such as bar charts and pie charts using food as a medium. For instance, Figure 3 is an edible stacked bar chart showing the amount of non-Finnish people living in Finland generated in a data cuisine workshop [28]. Nationalities of the immigrants are represented by the typical food of each corresponding country, e.g., salmon for the Swedish and rice for the Chinese.

To gain a better understanding of users' perception and behaviors with different styles of edibilization, we conducted a preliminary user study. We discuss the advantages and challenges of this novel experience with data from subjective feedback.

Preliminary User Study

We organized a "Data Tasting Workshop" with 15 participants to compare the differences between the visualization and edibilization of three distinct datasets.

Selected Datasets and Edibilization Design

We obtained three datasets together with the original visualizations from the Internet. The first dataset is about employment in agriculture in four Asian countries, namely, China, India, Japan and Korea.[1] We edibilized this data as savory cracker sauce, which is completely different from the original visualization – a geographic heatmap. Particularly, we exploitd the signature sauce of each country: thick broad-bean sauce for China, curry spread for India, wasabi paste for Japan, and Kimchi dip for Korean (Figure 4). The amount of sauce placed on a cracker depends on the size of agricultural population in the corresponding country. This edibilization is of the first style.

The second dataset compares the number of annual STEM degree earners with the number of annual STEM job openings.[2] The job opening data are from Bureau of Labor Statistics,[3] which is illustrated by a bar chart. We made a garden vegetable with ham salad to encode this data (Figure 4). More specifically, the bread crumbs at the bottom correspond to available jobs, salty ham represents associates degree/certificate holders, sweet corn kernels denote bachelors, diced sour tomatoes refer to masters, and bitter arugula symbolizes PhD graduates. We stacked the ingredients on top of one another in a transparent glass. The quantity of each ingredient reflects the value of the data entry. The final edibilization looks similar to a not-yet-blended salad, which evokes a flavor of an overlay bar chart.

The third dataset uses a pie chart to show the percentage of Asian Americans who see themselves as "very different from" versus "the same as" typical Americans, or in-between.[4] We used the appearance of the pie chart and replace the color patches with cheese cubes (Figure 4). Particularly, we mapped the percentages to the colors and tastes of the cheese: white as typical American, orange as

[1] Employment in agriculture. http://wdi.worldbank.org/table/3.2

[2] Degree data are from National Science Foundation. http://www.nsf.gov/statistics/seind12/appendix.htm

[3] Bureau of Labor Statistics. http://www.bls.gov/emp/

[4] Asian Americans. http://www.pewsocialtrends.org/asianamericans-graphics/

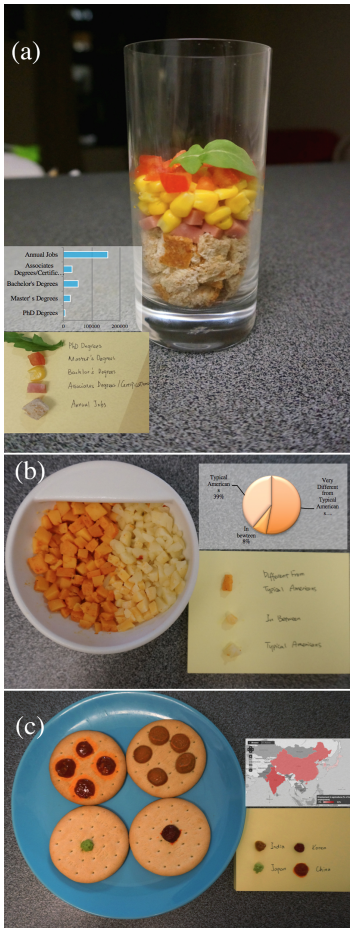

Figure 4: The edibilization for three different datasets.

the country of origin, and a mix of the two colors as biculturalism. This edibilization is of the second style.

Participants, Study Setup, and Procedure

We recruited 15 volunteers (ages ranged from 21 to 37, M=26, SD=3.5; 3 females) via advertisements posted in a local university for the data tasting workshop. All participants had used data visualization before.

At the beginning of the workshop, we informed the participants that we were experimenting with a new way to represent data without any specific instructions to study how users interact with edibilization naturally. Then, the participants were free to explore the three examples we provided. Each example consisted of a sheet of paper showing the title and visualization of the dataset, the edibilization we designed, and a legend plate with samples of all the ingredients used. The participants could pick up and observe the edibilization design closely, discuss with one another, and taste the "legend" at will (Figure 5).

We asked the participants to document their experience and write down detailed interpretations of each edibilization. At the end of the workshop, the participants rated to what extent edibilization is superior to visualization (or vice versa) on different attributes. We used a bidirectional Likert scale between -5 and 5 to measure their responses (Figure 6). We then conducted one-on-one semi-structured interviews to learn more about the perceived characteristics of data edibilization and its envisioned use. Based on the ratings and interview results, we summarize the advantages and challenges of data edibilization.

Advantages of Data Edibilization

Data edilization benefits from the psychological and behavioral effects from food.

Attractiveness

The participants of the preliminary study found data edibilization to be more attractive and attention grabbing than visualization (M = 3.8, SD = 1.37). Humans consider food as a means of survival. Thus, people are naturally attracted to food [12]. As time evolves, pleasant eating experiences further intensify the attentional and approach biases for food cues [7], especially when hunger strikes [38, 57], which is "a natural advantage (for edibilization) to attract people (P12, male)". Nearly all (13/15, 86.7%) of the participants agreed on that "It was close to lunch time, and thus your edibilizations were particularly eye/nose-catching (P14, male)."

The initial interest in an edibilization design can further become stronger approach tendencies toward the appetitive stimuli [7]. A total of 80% (12/15) of the participants found edibilization to be more aesthetically pleasing (M = 1.67, SD = 1.95), and 80% (12/15) considered edibilization to be more fun to explore (M = 2.33, SD = 2.92) than visualization. As one participant pointed out in the interview, "The cheese pie chart was quite straightforward, but the smell made me want to taste the ingredients to see if there were any hidden information (P15, female)."A palatable design can still "leave a good, deep impression (P1, male) even if the appearance is bland."

Sensory Richness

The above-mentioned quote suggests that the multi-sensory experiences triggered by food are attention catching and can be used to encode data [12]. We divide the sensory attributes of edible materials into two categories: 1) explicit visual-based attributes such as color, shape, and volume; and 2) implicit attributes including smell, taste, sound and texture, which may be less precise than visual cues [53, 30]. Designers can exploit the visual appeal of ingre-

Figure 5: The participants observing our data edibilization.

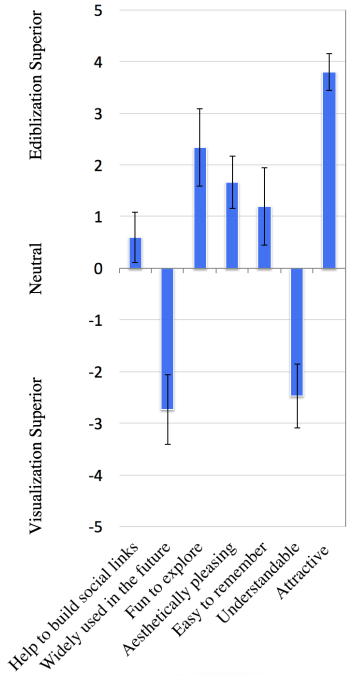

Figure 6: Overview of the rating results of the user study comparing the differences between data charts and data edibilization.

dients to convey prominent information, such as using the colors of cheese to denote cultural identity (Figure 4). In our interview, 53.3% (8/15) of the participants chose "appearance" as their first choice of properties to encode data if asked to design an edibilization.

The implicit attributes can serve as carriers of secretive or subtle messages such as emotions. As one participant said, "I was puzzled about how the ingredients were chosen for the different (STEM) degrees. When I took a bite of the (arugula) leaf – the representation of Ph.D. – and tasted the bitterness, I said to myself, this is why (P6, male, Ph.D. candidate)."Another participant wrote in her interpretation, "I notice that the texture and flavor of the white and mixed-color cheeses are more similar compared to the orange one. Maybe it means American and bicultural Asians can blend into the U.S. society better than those who maintain their ethnic identity (P10, female)." Overall, 80% (12/15) of the participants mentioned that they would encode data with implicit attributes in an edibilization design, five of whom even chose smell and taste as the primary communication channel. As one participant proposed, "Using various sensory attributes in conjunction to express the same meaning can make data analysis more accessible to visually-impaired people (P3, male)."

Intangible Richness

edibilization also contains rich intangible assets, such as culture [5], origin, and season of production, nutrition, brand, personal as well as social meanings, and so on. These assets can be leveraged to tell a lively data story. For instance, using cultural labels of edible materials can naturally denote geographic information, as done in edibilizing the agricultural employment data. One of the participants is from Thailand. He mentioned in the interview that "it would be even more interesting to me if you add Thailand to the dataset and put Thai curry or fish sauce on the plate (P11, male)." Another example is the interpretation of different ingredients in the STEM salad. Several participants associated the bread crumbles to job openings, relating it with the term "breadwinner", representing social meaning. Some thought associates' certification to be the only "meat" among all the degrees because it could yield greater strength and endurance for a larger population, representing nutrition. This can better engage users, induce positive emotions, and deepen their understanding of the data, especially when users capture information encoded by the implicit and intangible attributes. As a participant said in the post-workshop interview, "I suddenly understood what the designers wanted to say, which made me delighted (P2, male)." Overall, the rich sensory and intangible features constitute a large design space of data edibilization.

Memorability

Anthropologists have long discovered the ability of food to stimulate some of the deepest memories [60]. More than half (10/15, 66.7%) of the participants found the edibilization to be easier to remember than the charts on paper (M = 1.2, SD = 2.39). Memories of an edibilization design comprise the multi-sensory experiences triggered during the interaction with food [60]. Such memories can be subsequently evoked by the same or similar taste and smell [43, 44, 8]. Spherical concentric layer cake is a potential way to teach the interior structures of the Earth and the Jupiter using cakes.[5] Learners can slice and taste the different parts of the cakes. The embodied link between the texture and consistency of the cake layers and the actual physical properties of the concentric layers of the two planets make the knowledge particularly memorable. Previous

[5]Spherical Concentric Layer Cake. http://cakecrumbs.me/2013/08/01/spherical-concentric-layer-cake-tutorial/

studies have also postulated the material and intangible cultural account of food memories [60, 35]. When we asked the participants about what they remembered the most from the data tasting workshop, three participants mentioned the crackers with various sauces encoding different countries, because of the color contrast (appearance) and the feeling that they had captured the cultural hints intentionally embedded by the designers. This suggests that edibilization may exert a more enduring effect than the other types of data representations, which may potentially benefit application domains such as education and marketing.

Affectiveness

Prior research has suggested that associated emotions are another reason why food memories are powerful and long lasting [35]. First, people elicit more positive emotions, such as enjoyment, desire, and satisfaction [49], than negative affects when evoked by the experienced consequences of everyday interactions with edible products [16, 24]. Second, the sensory properties of food, particularly taste and smell, can stimulate a wide variety of emotions [16]. For example, the phrase “when things go sour" implies undesirable outcomes, while “this is really sweet” is meant to express pleasure [5]. Third, food intake contains affective metaphorical meanings [54]. One of the participants talked about his own experience. “In the annual retreat of the company that I interned in, we ate the pastry with our competitors’ performance data on the inked icing. It felt like expressing our wishes to outpace our competitors and become the leader in the market (P13, male)."Another participant shared an envisioned scenario. “Eating my (edibilized) academic record means that I have accepted, understood, and digested the results. I have turned the past into nutrition for the future, and now I can let it go (P8, female).”

The emotional effects of edibilization can potentially affect people’s behaviors and choices even long after exposure [44]. For example, presenting 3D printed cheerful messages and emoticons encoded with physical activity data, such as heart rate, in chocolate may encourage participation in physical activities [33].

Sociability

Food can facilitate social engagement [65, 24]. For example, family and friends enjoy chatting at dining table; dates are often arranged at lunch and dinner time; conference attendees usually socialize during coffee breaks. During our workshop, the edibilized representations triggered heated discussions among the participants. One person said, “We gathered and argued about the encoding scheme. We encouraged one another to sample the ingredients and share thoughts on the food and the data. It felt like deciphering some secret code together and was a lot of fun (P5, male)." As previous studies have proposed, eating, drinking, and food gifting are “the primary way of initiating and maintaining human relationships” [19, 45], especially when additional messages are embedded [63]. In general, 60% of the participants thought that edibilization can better strengthen social links than visualization (M = 0.6, SD = 1.88).

In summary, data edibilization has the potential to more effectively grab users’ attention, stimulate positive reactions and enduring memories, and encourage social interactions in comparison with the other conventional data presentation methods. However, we are also aware of the challenges of data edibilization as reflected in the preliminary study.

Challenges of Data Edibilization

A total of 86.7% of the participants found the edibilization to be not as easy to understand as visual charts for several possible reasons (M = -2.5, SD = 2.39). First, the participants were postgraduate students or teachers. Thus, they have been trained to read visual charts. By contrast, the

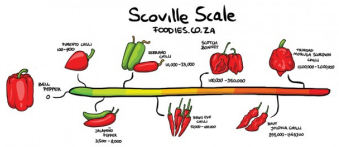

Figure 7: The Scoville Scale is the measurement of spiciness [18]. (© Foodies)

workshop was their first encounter with edibilization. Moreover, we did not provide any instructions on how to "read" the novel designs. Second, exploiting the implicit and intangible attributes of food introduces complexity and ambiguity. As a result, the participants sometimes felt that they might not be able to fully capture the designers' intent.

A total of 80% (12/15) of the participants shared their concerns with the scalability of data edibilization (M = -2.7, SD = 2.63), because they thought edibilizing data consumes more time, effort, and money, compared with plotting a chart. However, we argue that the emerging enabling technologies, such as 3D printing, can ultimately lower the cost and broaden the use of data edibilization in everyday life. We elaborate on this in the Enabling Techniques and Technologies section. In the following subsections, we discuss factors that might impair the efficacy of edibilization.

Food Literacy
Food literacy originally refers to the knowledge and ability to maintain a healthy diet [46]. We borrow this term to describe one's knowledge about food. If users have insufficient understanding of the materials used in the edibilization design, they might not be able to capture all the meanings and nuances of the representation. To avoid this problem, designers should select ingredients according to the food literacy of the target audience.

Preservation
Foods are perishable. Thus, designers must consider the preservation of data edibilization. Some ingredients may lose their original appearance such as apple slices turning brown, or texture, such as cookies getting soggy. To address these concerns, designers may take contextual conditions, such as humidity and the length of exhibition, into consideration. They may also choose materials that are less perishable, provide food samples exclusively for tasting, employ existing food preservation techniques [23], or prepare adequate backup ingredients.

Health/Sustainability Concerns and Dietary Constraints
Human beings can only intake a limited amount of food in a short period [48]. If designers want to exhibit or test a considerable number of data edibilizations, they might need to carefully calibrate the food list and relative portion sizes to not stuff the users or waste too much food. Data edibilization, may raise concerns about nutrition [37]. In addition, people may have various dietary constraints due to food allergy, health issues, culture, or religion [14]. Designers need to tailor their work based on the needs and constraints of the audience, ensuring that tasting their edibilization work is a healthy practice.

Sensory Capabilities
Humans vary in their sensitivity or tolerances to smells and tastes, which can be further affected by physical and psychological conditions, such as aging [26], or by personal eating habits and experiences. Designers should assign the senses to serve different purposes that can best fit and utilize the audience's capabilities. For example, smell is good for attracting attention because of its pervasiveness and endurance while taste has a wider spectrum with more distinguishable intensity levels such as the Scoville Scale for measuring spiciness (Figure 7 [56]).

To sum up, data edibilization has its natural entrance into people's lives. Compared with data visualization [40, 31], physicalization [58, 61, 27], and sonification [34, 22, 36, 47], data edibilization has a lower barriers of broad acceptance, and can create highly personalized experiences as well as social interactions around data. Even with the same design, data edibilization can convey different messages to different users by hiding certain information from people's eyes and ears and only disclose it to the targeted users. Therefore,

data edibilization has its unique value and is more beneficial in certain scenarios. Although edibilization alone cannot fulfill all the data communication tasks, and thus it is not a replacement of visualization,physicalization, and sognification, edibilization can be used in conjunction with other representations to provide richer experiences with data.

Pragmatic Process to Reach Data Edibilization

Thinking of how we can more easily design data edibilization of a given dataset is important. In this section, we propose three ways to realize data edibilization.

Food-based Approach: Data edibilization can be implemented by modifying the production process of common foods and dishes. For example, if we want to present data in a cup of coffee, we may select different coffee beans, change the amount of milk and sugar, tailor the thickness of foam, and serve it in various cups in accordance with the data, the users, and the scenarios. Utilizing the mature production process of common foods makes the design and implementation of data edibilization easier, given a confined design space. In addition, such use can minimize the risks of undesirable outcomes and makes performing trial and error less costly. Hence, automating this process becomes possible. Users may already have sufficient knowledge of the common food chosen. Nevertheless, this food-based approach has some obvious downsides. Its expressiveness is limited. Thus, it may not be able to convey complex data. Additionally, prior belief about and biases towards the selected food may hinder users' perception and imagination.

Data-driven Approach: A different data-driven approach aims to create novel edible representations of information, unrestricted by existing recipes. Designers first determine the dimensions of data that they want to convey. Then, they search for edible materials that can serve as the carriers. Finally, they use the selected ingredients to make a "dish", which may result in unexpected forms of food. Designers taking this approach have a larger design space, allowing them to handle more complex data. Although the resulting design may be less familiar to users, more abstract and difficult to understand, it may motivate people to explore. However, this data-driven approach entails higher risks, more decisions to make, and more trade-offs to balance.

Hybrid Approach: A third data edibilization design strategy combines the previous two methods to achieve the best of both worlds. Designers can either reinvent traditional dishes using non-traditional ingredients, or combine elements extracted from pre-specified cuisines to create an original dish. This eclectic hybrid approach seeks a balance between data and food, between feasibility and creativity.

Enabling Technologies

Recent development of technologies make it feasible to transform data edibilization design into practice.

Intelligent Food Production in the Era of IoT

Microcomputer controlled automatic cooking appliances turn input ingredients into dishes as programmed [11]. These cooking appliances can handle different ingredients and can produce different dishes based on the settings. The Internet of Things (IoT, a.k.a., the Network of Everything) more effectively connects automatic cooking appliances to their users via ubiquitous sensing and pervasive Internet [25, 6]. This technology allows the food production process to be directed by user data [32]. This method is beneficial for edibilization designers taking the food-based approach.

Data-driven Recipe Creation

Recipes are traditionally designed by professionals with adequate background knowledge about food and consumers.

Figure 8: A 3D *Marzipan Skyscraper* printed by 3D food printer. (© 2015 BOCUSINI)

Artificial Intelligence (AI) and Machine Learning (ML) techniques enables extracting food pairing principles [4] and automatically create new recipes. An example of such a system is the *IBM Chef Watson*.[6] By leveraging existing recipes and associated knowledge of food science and food industry, such as human taste preferences, food pairing theories, and flavor compounds, *Chef Watson* is able to use genetic algorithms to rearrange different elements, sort through a considerable number of possibilities, and deliver a list of creative recipes of flavorful dishes that satisfy users' needs [62]. Such methods can be applied in the data-driven and the hybrid approaches for data edibilization.

3D (Food) Printing

The emergence of 3D printing technology increases the feasibility of data edibilization. In particular, 3D printing can be made to create cooking tools and utensils for the production and consumption stages. An example is the banana slicers used as "data slicers" [1]. For another thing, 3D food printers [3, 64] make creative cooking practicable. Although still at its early stage, 3D food printing has demonstrated its potential to tailor meals by specifying parameters such as appearance, flavor, nutrients, ingredients, and so on [59]. For instance, the *Bocusini* food printer can print 3D marzipan-skyscraper sweets (Figure 8) as well as a wide variety of food products, such as dairy, meat, and vegetable. [7]

Research Agenda

A critical question on data edibilization is how to make the best use of this novel way of telling data stories. We propose that Human-Computer Interaction researchers can approach the problem from five directions, which is inspired by existing studies in related areas [27, 34, 39].

[6] IBM Chef Watson. https://www.ibmchefwatson.com/

[7] Bocusini. http://www.bocusini.com/

Algorithm and Technique: One critical research problem in edibilization is the transformation of data properties and relations into the perceived attributes of food and drinks. Designers may need to avoid interference between the smells/tastes of the ingredients in the same dish, as well as between several dishes displayed together. Moreover, personal and contextual factors add additional complexity to this problem [20]. These issues can be formulated as an optimization task. The design of algorithms and techniques for data-ingredient mapping directly determines the effectiveness of data edibilization.

Model: In addition to the design and evaluation of particular algorithms and techniques, meta-research on edibilization is necessary [51, 17, 42]. First, comprehensive models of the design space of data edibilization in different contexts for different users can be beneficial. Second, one can constructively propose new taxonomy of styles of making edibilization based on existing work. Third, providing guidance on the process of generating data edibilization can help designers thoroughly consider all aspects of user experiences. Reflective observations and creative thinking about the process would inspire novel, effective designs with manageable costs.

System: Designers need system support to realize data edibilization. With algorithms and models running in the backend, authoring tools may help designers pick proper ingredients, simulate and compare various mapping options, and construct a selected data recipe. Once designers settle on an edibilization design, they can program the manufacturing systems to follow the specific production process, transforming the corresponding ingredients into a data dish. This process may include customizing the physical forms of materials, such as cutting and grinding, adding proper seasoning, and applying additional treatments. All these steps

require precise control. Even so, the final product may not turn out as planned. Therefore, a good manufacturing system should be efficient, fexible, and interactive to facilitate fast prototyping and debugging.

Evaluation: Considering that edibilization is a novel way to communicate data to humans, generally ordinary people, understanding how users perceive and interact with data edibilization is important for many reasons. Researchers can conduct comparative studies to investigate the advantages and challenges of edibilization in comparison with other means of data communication, such as visualization and physicalization. A follow-up question is whether and how edibilization can be used in conjunction with other representations to tell a better data story.

Application: Researchers and practitioners can deploy data edibilization in various application domains. One example is the use of edibilization in marketing as an augmentation or even a replacement of conventional charts and tables. Other possible domains include entertainment, education, healthcare, and public relations, as proposed by the workshop participants. Many research questions related to edibilization applications arise. The application scenarios should be further studied to set the criterion for using data edibilization based on domain knowledge. Moreover, they should be studied to determine the applicability of data edibilization and to understand how to better utilize this technique. For certain applications, designers can also exploit virtual/augmented reality technologies [9, 41], holographic displays [13] and digital taste and smell [50] to further increase immersion in data edibilization. We can even expect that data edibilization can be pervasive in daily life. Researchers may explore the possibilities of using data edibilization in various scenarios to make it more accessible and widely used.

Conclusion and Future Work

In the paper, we proposed to define a new concept as “data edibilization”, which is the use of edible materials to convey stories in data. We conducted a preliminary study to explore people’s perception and behaviors of data edibilization, and discuss the advantages, challenges, and opportunities of this novel data representation. Then, we proposed three strategies of edibilization design, namely, food-based, data-driven, and an eclectic combination of these two methods. We reviewed the enabling technologies of edibilization and highlighted the potential of data edibilization in comparison to the existing data representations such as visualization, sonification, and physicalization. We discussed possible research directions related to data edibilization.

Our exploration of this new means of communicating data is still at an early stage. The examples used in our preliminary study were relatively simple, which have not yet fully demonstrated the potential of edibilization to users. As proposed in the Research Agenda section, in the future, we plan to conduct more systematic experiments to investigate how people interact with data edibilization, in comparison with or in conjunction of other media, in a controlled environment or in the wild. We aim at building a platform to facilitate (collaborative) design and production of data edibilization, and broaden its use in various application domains.

Acknowledgements

The authors would like to thank the all the reviewers who wrote and provided helpful comments on our paper and all the study participants for their support. This work is partially supported by the National Basic Research Program of China (973 Program) under Grant No. 2014CB340304.

References

[1] 2014. Taste of data. Retrieved June 30, 2015 http://taste-of-data.tumblr.com/. (2014).

[2] 2016. The center for genomic gastronomy. Retrieved December 29, 2015 http://genomicgastronomy.com/. (2016).

[3] 3DPI. 2015. 3D printing industry. Retrieved September 2, 2015 from http://3dprintingindustry.com/food/, (2015).

[4] Yong-Yeol Ahn, Sebastian E Ahnert, James P Bagrow, and Albert-László Barabási. 2011. Flavor network and the principles of food pairing. *Scientific reports* 1 (2011).

[5] Peter Atkins, Ian Bowler, and others. 2001. *Food in society: economy, culture, geography*. Arnold, Hodder Headline Group.

[6] Luigi Atzori, Antonio Iera, and Giacomo Morabito. 2010. The internet of things: A survey. *Computer networks* 54, 15 (2010), 2787–2805.

[7] Tanya Griffiths Brendan P. Bradley Brignell, Catherine and Karin Mogg. 2009. Attentional and approach biases for pictorial food cues: Influence of external eating. *Appetite* 52, 2 (2009), 299–306.

[8] Gemma Calvert, Charles Spence, and Barry E Stein. 2004. *The handbook of multisensory processes*. MIT press.

[9] Julie Carmigniani, Borko Furht, Marco Anisetti, Paolo Ceravolo, Ernesto Damiani, and Misa Ivkovic. 2011. Augmented reality technologies, systems and applications. *Multimedia Tools and Applications* 51, 1 (2011), 341–377.

[10] Austin Carr. 2014. IBM'S Watson Food Truck Brings the Supercomputer to the Kitchen. Retrieved August 10, 2015 from http://www.fastcompany.com/3027446/tech-forecast/ibms-watson-food-truck-brings-the-supercomputer-to-the-kitchen. (2014).

[11] Mario G Ceste Sr. 1989. Temperature control system for cooking apparatus. (March 14 1989). US Patent 4,812,625.

[12] Helen Charley and Connie Weaver. 1998. *Foods: a scientific approach*. Merrill.

[13] Robert Collier. 2013. *Optical holography*. Elsevier.

[14] Rob Comber, Eva Ganglbauer, Jaz Hee-jeong Choi, Jettie Hoonhout, Yvonne Rogers, Kenton O' Hara, and Julie Maitland. 2012. Food and interaction design: designing for food in everyday life. In *CHI'12 Extended Abstracts on Human Factors in Computing Systems*. ACM, 2767–2770.

[15] Alan R Dennis and Joseph S Valacich. 1999. Rethinking media richness: Towards a theory of media synchronicity. In *Systems Sciences, 1999. HICSS-32. Proceedings of the 32nd Annual Hawaii International Conference on*. IEEE, 10–pp.

[16] Pieter MA Desmet and Hendrik NJ Schifferstein. 2008. Food, memory and meaning: the symbolic and social nature of food events. *Appetite* 50, 2 (2008), 290–301.

[17] Tanja Döring, Axel Sylvester, and Albrecht Schmidt. 2013. A design space for ephemeral user interfaces. In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction*. ACM, 75–82.

[18] Pat Elk. 2013. How hot is too hot when it comes to chillies? http://www.foodies.co.za/how-hot-is-too-hot-when-it-comes-to-chillies/. (2013).

[19] Peter Farb and George Armelagos. 1980. *Consuming passions, the anthropology of eating*. Houghton Mifflin.

[20] Ingrid C. Fedoroff, Janet Polivy, and C Peter Herman. 1997. The effect of pre-exposure to food cues on the eating behavior of restrained and unrestrained eaters. *Appetite* 28, 1 (1997), 33–47.

[21] David G. Myers and C. Nathan DeWall. 2015. *Psychology, 11th Edition*. Worth Publishers.

[22] William W. Gaver. 1993. What in the world do we hear? An ecological approach to auditory event perception. *Ecological Psychology* 5, 1 (1993), 1–29.

[23] Grahame Warwick Gould. 2012. *New methods of food preservation*. Springer Science & Business Media.

[24] Andrea Grimes and Richard Harper. 2008. Celebratory technology: new directions for food research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 467–476.

[25] Jayavardhana Gubbi, Rajkumar Buyya, Slaven Marusic, and Marimuthu Palaniswami. 2013. Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems* 29, 7 (2013), 1645–1660.

[26] Alessandra Imoscopi, Emine Meral Inelmen, Giuseppe Sergi, Fabrizia Miotto, and Enzo Manzato. 2012. Taste loss in the elderly: epidemiology, causes and consequences. *Aging Clinical and Experimental Research* 24, 6 (2012), 570–579.

[27] Yvonne Jansen, Pierre Dragicevic, Petra Isenberg, Jason Alexander, Abhijit Karnik, Johan Kildal, Sriram Subramanian, and Kasper Hornbæk. 2015. Opportunities and challenges for data physicalization. In *In Proceedings of the 33nd annual ACM conference on Human factors in computing systems*.

[28] Susanne Jaschko and Moritz Stefaner. 2014a. Data cuisine. http://data-cuisine.net/, (2014).

[29] Susanne Jaschko and Moritz Stefaner. 2014b. Data cuisine: Resources and reference projects. Retrieved December 30, 2015 http://data-cuisine.net/resources-and-reference-projects/. (2014).

[30] Joseph'Jofish' Kaye. 2004. Olfactory display. In *Proceedings of the 17th annual ACM symposium on User interface software and technology*. ACM, 163–163.

[31] Daniel Keim and others. 2002. Information visualization and visual data mining. *Visualization and Computer Graphics, IEEE Transactions on* 8, 1 (2002), 1–8.

[32] Rohit Ashok Khot, Jeewon Lee, Deepti Aggarwal, Larissa Hjorth, and Florian'Floyd' Mueller. 2015a. TastyBeats: Designing Palatable Representations of Physical Activity. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 2933–2942.

[33] Rohit Ashok Khot, Ryan Pennings, and Florian Floyd Mueller. 2015b. EdiPulse: supporting physical activity with chocolate printed messages. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*. ACM, 1391–1396.

[34] Gregory Kramer, Bruce Walker, Terri Bonebright, Perry Cook, John H Flowers, Nadine Miner, and John Neuhoff. 2010. Sonification report: Status of the field and research agenda. (2010).

[35] Deborah Lupton. 1994. Food, memory and meaning: the symbolic and social nature of food events. *The Sociological Review* 42, 4 (1994), 664–685.

[36] Taram Madhyastha, Daniel Reed, and others. 1995. Data sonification: Do you see what I hear? *Software, IEEE* 12, 2 (1995), 45–56.

[37] L. Kathleen Mahan and Sylvia Escott-Stump. 2004. Krause's food, nutrition, & diet therapy. (2004).

[38] Karin Mogg, Brendan P Bradley, Harpfreet Hyare, and Sui Lee. 1998. Selective attention to food-related stimuli in hunger: are attentional biases specific to emotional and psychopathological states, or are they also found in normal drive states? *Behaviour Research and Therapy* 36, 2 (1998), 227–237.

[39] Tamara Munzner. 2008. Process and pitfalls in writing information visualization research papers. In *Information visualization*. Springer, 134–153.

[40] Tamara Munzner. 2014. *Visualization Analysis and Design*. CRC Press.

[41] Takuji Narumi, Yuki Ban, Takashi Kajinami, Tomohiro Tanikawa, and Michitaka Hirose. 2012. Augmented perception of satiety: controlling food consumption by changing apparent size of food with augmented reality. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 109–118.

[42] Marianna Obrist, Rob Comber, Sriram Subramanian, Betina Piqueras-Fiszman, Carlos Velasco, and Charles Spence. 2014a. Temporal, affective, and embodied characteristics of taste experiences: A framework for design. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*. ACM, 2853–2862.

[43] Marianna Obrist, Alexandre N Tuch, and Kasper Hornbæk. 2014b. Opportunities for odor: experiences with smell and implications for technology. In *Proceedings of the 32rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 2843–2852.

[44] Nicole Koenig-Lewis Adrian Palmer Organ, Kate and Jane Probert. 2015. Festivals as agents for behaviour change: A study of food festival engagement and subsequent food choices. *Tourism Management* 48 (2015), 84–99.

[45] Susan J Paxton, Helena K Schutz, Elenor H Wertheim, and Sharry L Muir. 1999. Friendship clique and peer influences on body image concerns, dietary restraint, extreme weight-loss behaviors, and binge eating in adolescent girls. *Journal of Abnormal Psychology* 108, 2 (1999), 255.

[46] Donna Pendergast, Susanne Garvis, and Harry Kanasa. 2011. Insight from the public on home economics and formal food literacy. *Family and Consumer Sciences Research Journal* 39, 4 (2011), 415–430.

[47] Loshak-A. Backhaus S. Davis J. C. Pereverzev, S. V. and R. E. Packard. 1997. Quantum oscillations between two weakly coupled reservoirs of superfluid 3He. *Nature* 388 (1997), 449–451.

[48] University A DJ Catholique de Louuain Pharmaceutiques. 1995. Dietary modulation of the human colonie microbiota: introducing the concept of prebiotics. *Journal of Nutrition* 125 (1995), 1401–1412.

[49] Elizabeth Taylor Quilliam. 2008. *Happy meals, happy parents: Food marketing strategies and corporate social responsibility*. ProQuest.

[50] Nimesha Ranasinghe, Kasun Karunanayaka, Adrian David Cheok, Owen Noel Newton Fernando, Hideaki Nii, and Ponnampalam Gopalakrishnakone. 2011. Digital taste and smell communication. In *Proceedings of the 6th International Conference on Body Area Networks*. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 78–84.

[51] JC Roberts and R Walker. 2010. Using all our senses: the need for a unified theoretical approach to multisensory information visualization. In *Workshop on the Role of Theory in Information Visualization*.

[52] Jonathan C Roberts, Panagiotis D Ritsos, Sriram Karthik Badam, Dominique Brodbeck, Jessie Kennedy, and Niklas Elmqvist. 2014. Visualization beyond the Desktop–the Next Big Thing. *Computer Graphics and Applications, IEEE* 34, 6 (2014), 26–34.

[53] Paul Rozin. 1982. "Taste-smell confusion" and the duality of the olfactory sense. *Attention, Perception, & Psychophysics* 31, 4 (1982), 397–401.

[54] Paul Rozin. 1996. Towards a psychology of food and eating: From motivation to module to model to marker, morality, meaning, and metaphor. *Current Directions in Psychological Science* (1996), 18–24.

[55] Chloé Rutzerveld. 2014. Edible growth. Retrieved July 1, 2015 http://www.chloerutzerveld.com/edible-growth-2014/. (2014).

[56] Wilbur L Scoville. 1912. Note on capsicums. *Journal of the American Pharmaceutical Association* 1, 5 (1912), 453–454.

[57] Edgar Soria-Gómez, Luigi Bellocchio, Leire Reguero, Gabriel Lepousez, Claire Martin, Mounir Bendahmane, Sabine Ruehle, Floor Remmers, Tifany Desprez, Isabelle Matias, and others. 2014. The endocannabinoid system controls food intake via olfactory processes. *Nature Neuroscience* 17, 3 (2014), 407–415.

[58] Simon Stusak, Aurélien Tabard, Franziska Sauka, Rohit Ashok Khot, and Andreas Butz. 2014. Activity sculptures: Exploring the impact of physical visualizations on running activity. *Visualization and Computer Graphics, IEEE Transactions on* 20, 12 (2014), 2201–2210.

[59] Jie Sun, Weibiao Zhou, Dejian Huang, Jerry YH Fuh, and Geok Soon Hong. 2015. An Overview of 3D Printing Technologies for Food Fabrication. *Food and Bioprocess Technology* (2015), 1–11.

[60] David E. Sutton. 2001. *Remembrance of repasts: an anthropology of food and memory*. Berg Publishers.

[61] Saiganesh Swaminathan, Conglei Shi, Yvonne Jansen, Pierre Dragicevic, Lora A Oehlberg, and Jean-Daniel Fekete. 2014. Supporting the design and fabrication of physical visualizations. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*. ACM, 3845–3854.

[62] Lav R Varshney, Florian Pinel, Kush R Varshney, Debarun Bhattacharjya, Angela Schoergendorfer, and Yi-Min Chee. 2013. A big data approach to computational creativity. *arXiv preprint arXiv:1311.1213* (2013).

[63] Jun Wei, Xiaojuan Ma, and Shengdong Zhao. 2014. Food messaging: using edible medium for social messaging. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*. ACM, 2873–2882.

[64] Kyle Wiggers. 2015. Why 3D food printing is more than just a novelty. Retrieved July 8, 2015 from http://www.digitaltrends.com/cool-tech/3d-food-printers-how-they-could-change-what-you-eat/, (2015).

[65] L Wright, M Hickson, and G Frost. 2006. Eating together is important: using a dining room in an acute elderly medical ward increases energy intake. *Journal of Human Nutrition and Dietetics* 19, 1 (2006), 23–26.