Design of Cyber Food:

Beginning to Understand Food as Computational Artifact

JIALIN DENG*

Exertion Games Lab, Department of Human-Centred Computing, Monash University, Melbourne, Australia,

jialin.deng@exertiongameslab.org

PATRICK OLIVIER

Action Lab, Department of Human-Centred TechnologyMonash University, Melbourne, Australia, patrick.olivier@monash.edu

FLORIAN 'FLOYD' MUELLER

Exertion Games Lab, Department of Human-Centred Computing, Monash University, Melbourne, Australia,

floyd@exertiongameslab.org

With a growing interest in HCI around food, there is a trend to combine computing technology and food to facilitate novel eating experiences. However, most current systems tend to superimpose the technology over food rather than consider food itself as a focal interaction material. This paper proposes a more direct computational food integration by conceptualizing the notion of "Cyber Food", accentuating "food as computational artifact", where food embodies digital computation that can be ultimately consumed and digested by the human body. With this work, we attempt to open a new pathway to enrich human-food interactions beyond the traditional boundaries between the physical (edible) and digital realms.

CCS CONCEPTS • Human-centered computing • Interaction design

Additional Keywords and Phrases: Food, Eating, Human-Food Interaction

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1 INTRODUCTION

The increasing availability of computing technology offers new ways of supporting our food-related practices [5, 6, 21-25]. The efforts on the exploration of digital engagement around eating have been increasingly studied in the domain of Human-Food Interaction (HFI) within the HCI community [11, 25]. However, to date, most engagement with eating experiences relies on multimedia augmentation superimposed over or around the food [43]. For example, prior work installed equipment such as projectors, speakers, and lights around food [2, 9, 14, 15]; connected mobile phones, sensors, and AR/VR HMDs with the food [10, 12, 13, 37]; or hid digital devices inside the cutlery [38, 51]. We believe that such systems emphasize positioning technology around existing foodstuff, rather than considering food itself as interactive design material, that is, as distinct interactive material of design. The problem with this traditional approach is, we believe, that resulting experiences are critically dependent on digital devices rather than on the experiential affordances of food. We consider such interactions between humans and food only loosely linked with each other. Aiming to move beyond such approaches, we seek a more “direct” computational integration with food, that is, a future where the unique properties of food are integrated with the digital world. For this, we conceptualize “Cyber Food”, where food mediates new forms of computing technology and is regarded as the focal “material-concern” [53] of interaction design.

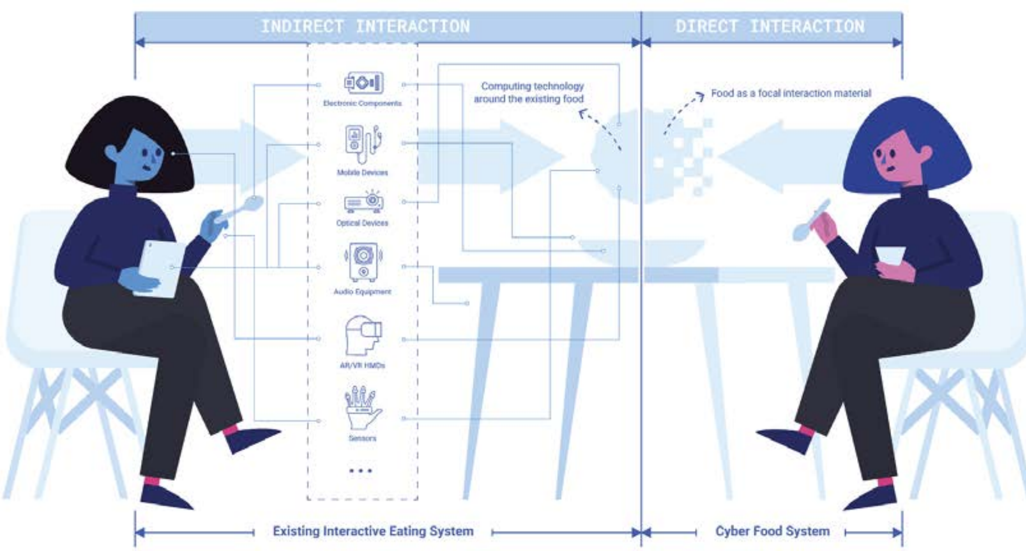

Figure 1: Existing interactive eating systems are considered an “indirect” interaction; “Cyber Food” systems are considered a “direct” interaction

Computer-engineered food or employing digital machines in preparing food is a related topic [8, 60] that encompasses digital gastronomy and 3D food-print technology [16] to create food that represents digital information [21], enables deformable mechanism [48], and enriches food-related practices [32]. Furthermore, emerging food-based edible electronics and ingestible devices [7, 28, 56] have opened up an interwoven future of food and computing technology. However, most of these technologies and associated systems maintain an essentially instrumental perspective on human-food interactions, optimizing, for example, medical or health benefits. By contrast, there is a shortfall in empirically-informed knowledge of how such an integrated approach can enrich eating experiences from an experiential perspective.

This poses the question of *How do integrated food interactions affect people's eating experiences?* To answer this question, it is necessary to study and design what we refer to as "Cyber Food", by highlighting food as computational artifact, we define "Cyber Food" as:

Food that can perform a digital function or logic operation allowing for conditioned changes to be expressed by its physical properties.

Inspired by how tangible bits [18, 47] bridges the digital and physical highlighting the tangibility of computation, we attempt to design a synergistic interplay between food and technology by engaging with food's material properties. The aim is to facilitate a human-food integration beyond the traditional boundaries between the physical and digital realms. Also, Wiberg et al. [54] propose that the compositions of digital and physical materials offer a huge potential in advancing HCI by offering new user experiences. We thus hope that the "Cyber Food" facilitates such experiential perspectives with new experiences around eating.

Our goal is to explore and inspire a new design space for a variety of stakeholders across the HCI research community, and a broad range of industrial sectors. We hope to offer an understanding of how to couple food and digital computation to aid interaction designers and food designers when aiming to create novel food interactions. We also aim to provide guidance for food producers, culinary practitioners, chefs, and restaurateurs to create engaging dining experiences. Moreover, we aim to provide a structured understanding of Cyber Food for researchers across HCI, electronics engineering, soft robotics, and material science to use as scaffolding to study ingestible and biocompatible composites as well as associated experiences.

Therefore, we will design and conduct studies with "Cyber Food" in order to gain a systematic understanding of the associated eating experiences. The studies will help to iteratively refine the understanding of the design of "Cyber Food", leading to additional prototypes. In order to further explain what we mean by "Cyber Food", we offer a comparison between the "Cyber Food" system and existing augmented eating systems. Both systems have unique advantages and disadvantages (Table 1), and next, we articulate a dimension with four taxonomy groupings as a trajectory for our vision.

Characteristic	**Cyber Food System**	**Existing Augmented Eating Systems**
Prior work examples	• Digital gastronomy [59] • Transformative appetite [48] • Edible electronics [55]	• MetaCookie+ [35] • iScream [50] • Bottle+ and Spoon+ [50]
Relationship between food and digital computation	Food is a focal interaction material	Mainly using existing food source
Interplay between food and digital computation	Synergistic with each other	Physically independent from each other

Manipulation	Direct manipulation by instinctive behavior: eating	Mostly relies on operating additional devices: VR/AR, sensors, wearables, etc.
Feedback	Synchronized with every bite of food	“Pseudo-real-time” feedback by computational simulation
Availability	One-time interaction according to the size of food	In most cases, digital interaction will still be available even if the food is eaten
Robustness	The system can be consumed or deteriorate, and is not reusable	The digital part can exist for longer and is often reusable

Table 1: Comparison between “Cyber Food” system and existing eating augmentation systems.

2 RELATED WORK

There has been a longstanding interest in HCI and design in the relationship between food and computing technology. We articulate a dimension derived from an analysis of related work. The dimension indicates how food can be fabricated to be inextricably linked to computational technology. It shows from left to right how food can be employed as a simple material substrate towards a complex manifestation of digital functions. We position prior work along this dimension, resulting in a taxonomy of prior systems within four groupings, 1) *Representation*: food as an embodiment of digital information; 2) *Transformation*: food as shape-changing interface; 3) *Electronization*: food as edible electronics; 4) *Computation*: food as cybernetic systems.

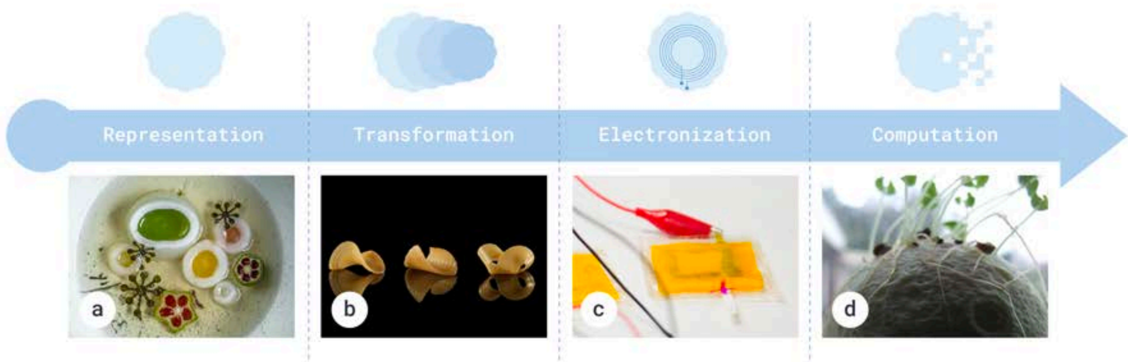

Figure 2: Dimension with four key taxonomy groupings: Representation, Transformation, Electronization, Computation. a) 3D-printed soup dish representing culinary variables generated by digital computation ©Digital Gastronomy [1, 59]; b) Autonomous transformations of food during cooking [48, 52]; c) An edible supercapacitor made out of food ©ASU Now [44, 49]; d) Computers from plants. Using the bioprocess of basil roots to develop transport networks [3].

2.1 Representation: food as an embodiment of digital information

The *Representation* grouping entails systems where food is a material manifestation of digital information that diners can interact with. Employing digital data in food can now go beyond traditional capabilities thanks to the advances of computer-engineered food [8, 34, 59-61]. For example, Zoran developed a vision of Digital Gastronomy (DG) [59] by showcasing dishes fabricated with parametric design tools, including a robot-arm-printed pho soup (Fig.2a), and two desserts made of programmable modular mould [1, 61]. This research revealed how digital computation can be integrated into kitchens enabling food as a representation of "culinary variables (tastes, textures, temperature, duration, etc.)" [59]. Another example is "Cyber Wagashi [29]" which that uses traditional Japanese confectionery pieces to represent weather data [29] by mapping three major weather data points (windspeed, atmospheric pressure, and temperature) into the "culinary variables (size and shape, height, and color)" of 3D-printed wagashi. These projects demonstrated how food can be designed to represent digital information. However, as these were not accompanied by user studies, there is still a lack of knowledge of the associated user experience, which would help inform an understanding of the design of future systems. Interestingly, more recently, prior work has emerged that went from static to non-static representations, resulting in what is called transformative food, which we explain next.

2.2 Transformation: food as shape-changing interfaces

The *Transformation* grouping entails systems where food transforms its configuration or function (e.g. shape, structure, movement) over time in response to external stimuli (e.g. temperature, light, etc.). This has been enabled in particular through advancements around transformable materials [36, 58], 4D printing [33], and robotics [26, 30, 31] combined with newly emerging biocompatible materials [20, 45, 46, 48, 57]. For example, the system "Transformative Appetite" presents pasta (Fig.2b) in flat form that transforms into a 3D structure during cooking [48]. Similarly, Tao et al. [46] developed a shape-changing flour-based dough for morphing food by dehydration (e.g. baking) or hydration (e.g. water boiling). From these works, we learn how static food interfaces turned into shape-changing food interfaces, enabling novel interactions where the experience changes over time. However, what we still do not know much about is how users experience these systems, and hence our knowledge about how to design systems that users find engaging is incomplete.

2.3 Electronization: food as edible electronics

The *Electronization* grouping entails food as electronic components and devices embodying computational functions. Emerging devices fabricated using ingestible materials have enabled the possibility of designing food as edible digital devices [7, 27]. There are already microprocessors that can be swallowed, however, so far, they get excreted as they cannot be digested by the human body [19, 56], However, more recently, research has developed food-based edible electronics to advance this field. For example, Xu et al. developed edible devices made out of food, including edible supercapacitors (Fig.2c) [49], a pH sensor, a radio frequency filter, and a microphone [55]. This work reveals how food-based materials can be fabricated to be functional electronic devices. However, it is still unclear how such edible electronics would affect the eating experience.

2.4 Computation: food as cybernetic systems

We use the *Computation* grouping to refer to logic and finding solutions through algorithms [17] via foodstuff. For example, a number of plants (known as "food crops") are recognized as intelligent organisms, as they continuously sense information from the environment and make decisions to regenerate, actuate or grow in response (Fig.2d) [3, 41, 42]. Hence prior work has proposed to develop computing systems made out of plants, including basil roots as morphological computing devices [4], and tomato seeds as computationally maze-solving agents [39]. Furthermore, the "Cyborg Botany" concept showcases a set of computational devices by turning plants into a touch sensor, motion sensor, antenna, and display by utilizing the plant's bioprocesses [41]. Moreover, the project "Future Food Formula" speculates on a future around customizable vegetables with adjustable growth parameters such as shape, taste, and nutritional value [40]. These works suggest how to design a system bridging biological operations with the digital world. However, there is still a gap between these systems and their users, that is, a lack of exploration of looking into the associated user experiences.

To sum up, our review has identified that prior research has already begun to fabricate food as computational “products” in various ways. However, food is mostly still not placed as the focal “material concern” for mediating new forms of interaction design. Furthermore, most prior works did not focus on the experiences of eating with these systems, and hence there is a lack of understanding of how those systems affect the eating experience, which, we believe, is important to gain for the design of future systems.

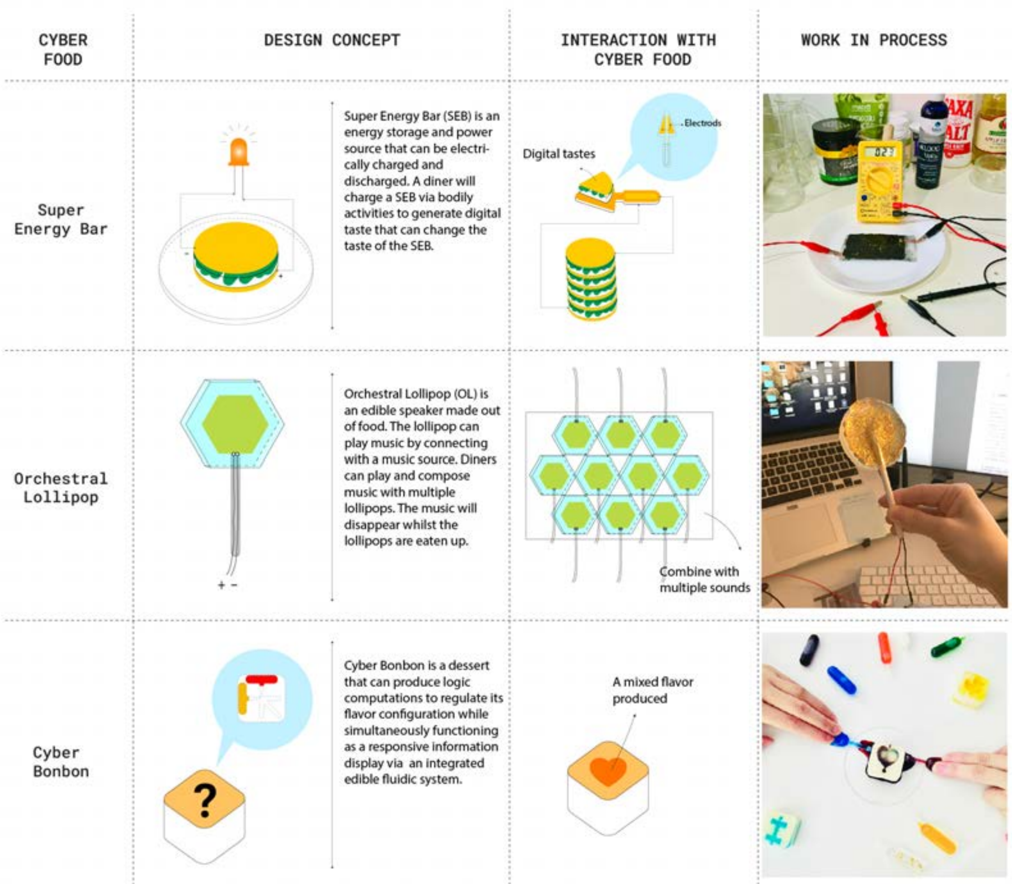

Table 2: Design Concepts for possible interactions facilitated by “Cyber Food”.

3 FUTURE WORK

In future work, we will conduct our research by designing prototypes of “Cyber Food” system and study how people engage with them in an eating scenario. We now present three of our current design concepts of “Cyber Food”: Super Energy Bar, Orchestral Lollipop and Cyber Bonbon (Table 2). Through our design, we will nail down and articulate a design space that delineates the design primitives of food as computation artifact.

Furthermore, we aim to produce design strategies that aim to help designers and culinary practitioners navigate this design space to create novel dining experience with "Cyber Food".

4 CONCLUSION

By describing "food as computational artifact", the notion of "Cyber Food" aims to bridge the edible and the digital realm via a more direct interaction between food and computing technology. The aim is to fully unlock the potential of computation when it comes to food and enrich human-food interactions beyond the traditional boundaries between the physical (edible) and digital realms. In this article, we presented a comparison between existing augmented eating systems and "Cyber Food" to help researchers, designers, and culinary practitioners to understand this emerging area of food and computation. Furthermore, we presented a dimension that helps group prior works that took an outset to augmented and embedded digital technologies in food. We see "Cyber Food" as complementing existing approaches to designing interactive eating systems. With "Cyber Food", we aim to explore a new approach for novel eating experiences. Next, we will develop a set of "Cyber Food" systems and carry out associated user studies to unpack the user experiences, focusing on an experiential perspective.

With our work, we hope to produce a structured understanding of how to design "Cyber Food", enriching human-food interactions beyond the traditional boundaries between the physical (edible) and digital realms.

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