Dancing Delicacies: Designing Computational Food for Dynamic Dining Trajectories

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ABSTRACT

Contemporary human-food interaction design is often a technology-driven endeavor in which food's materiality has been largely underexplored. Building on the concept of "computational food", this paper explores the design of food as a material realization of computation through a material-centered approach. We engaged with a "Research through Design" exploration by designing a computational food system called "Dancing Delicacies", which enables food items to be "programmed" and "reconfigured" within dynamic trajectories. Our practice led to a design framework resulting in four original dish designs. Our dishes aim to illustrate the richness of this new design space for computational food. Furthermore, through engaging with expert practitioners from the hospitality industry, we provide a first account of understanding the design of computational food for dynamic dining trajectories and its speculative use contexts in the industry. With this work, we hope to inspire researchers and designers to envision a new future of human-food interaction.

CCS CONCEPTS

• **Human-Centered Computing**; • **Interaction Design**;

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KEYWORDS

Human-food interaction, Computational food design, Dynamic trajectories

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1 INTRODUCTION

Explorations in the HCI field have led to greater convergence between food and computing technology, giving rise to an emerging research field: Human-Food Interaction (HFI) [7, 20, 21, 23, 26, 44]. However, the current research agenda in HFI appears to be primarily driven by technological novelty and efficiency [24, 25], rather than food's material affordances [29]. Interestingly, we noted that culinary practitioners have long been experimenting with food's materiality by exploiting and manipulating food's physical and chemical properties [77], resulting in innovations in new cuisines and "magical" food experiences [74]. However, many HFI designs fall short when it comes to "celebrat[ing] the pleasurable and enjoyable experiences that people have with food" [34], which are often derived from the food material's properties emphasizing the aesthetic, affective, sensual and sociocultural qualities of food [81, 82, 89].

Nevertheless, prior research has proposed an emerging notion of "computational food" and initially envisioned a future where food as a material is computationally transformable and reconfigurable [8, 42]. Drawing on this vision, researchers proposed the "material integration" where food is seen as a material that mediates

Figure 1: An exemplar dish of Dancing Delicacies.

the realization of computation [22, 25, 27]. This approach led to the creation of a series of computational desserts that can react to simple inputs with basic logic operations because of the integrated functionality within the desserts' physical structures [25]. This work suggested that the changes in food's states via computation could enrich people's engagements with food, yet only focused on a single "one-off" interaction for diners (akin to a button toggle). Therefore, we aim to extend the prior work from a one-off configuration toward more temporal processes of food that could behave dynamically in response to multiple operations.

In this paper, we engaged with a "Research through Design" (RtD) [95] process to investigate dynamic trajectories in food creation and consumption by creating a computational food system called "Dancing Delicacies". The system enables food items to be "programmed" and "reconfigured" through a series of dynamic operations (Section 4). Specifically, through "programming", a food creator can define the setting of the starting conditions of a dish and its dynamic behaviors (i.e., moving trajectories), and through configuring, a diner is offered several parameters to control the food process according to the settings defined by the creator (e.g., letting diners to change the food layout or combine different flavors). We present a design framework encompassing two dimensions related to dynamic trajectories when designing computational food: "level of control" and "gastronomic value". Furthermore, to explore how our framework facilitates new ways of designing computational food, we created four exemplar Dancing Delicacies dishes illustrating four distinctive design directions and their implications (Section 5). Lastly, we used our design to explore speculative use contexts through a preliminary engagement with expert practitioners (N=5) from the hospitality industry (Section 6).

Taken together, our contributions include:

- A new system for computational food designs that facilitates dynamic dining trajectories via "programming" and "reconfiguring" food items.
- A design framework depicting a new space of computational food that could serve as a basis for critically analyzing and understanding computational food designs.
- Four exemplar "Dancing Delicacies" dish designs suggesting multiple design directions concerning future design possibilities of dynamic dining trajectories within computational food.
- Seven themes derived from a preliminary engagement with hospitality experts that provide a first account of understanding the design of computational food for dynamic dining trajectories and its speculative use contexts in the industry.

2 RELATED WORK

2.1 Approaches to current HFI design

There has been a notable increase of works in HFI highlighting the possibilities enabled by technology to impact our food practices and experiences [7, 20, 21, 23, 26, 44]. HFI researchers have begun experimenting with emerging technologies such as 3D-printing [47, 76], virtual reality [10], capacitance sensing [37, 87, 88], robotics [58], electrical muscle stimulation [65], acoustic levitation [83, 84], and shape-changing interfaces [66, 86]. These developments are supplemented by smart kitchens [59] and appliances [51, 76] that enable enhanced food preparation processes. At the same time, smartphone apps employ artificial intelligence to track users' diets (e.g., calorie consumption) by automatically identifying food items and computing the recommended volume and nutritional information [69].

We note that these existing HFI works are often a technology-driven endeavor highlighting the functionality and novelty of computing technology. However, such endeavors might only be one of the many approaches through which food and technology design could be equally engaged. Indeed, Comber et al. [19] argued that HFI should pay much more attention to the people and how they engage with food than the efficiencies and novelties new technologies may offer. Echoing this, we note that the inherent affordances of food still appear to be overlooked in existing HFI approaches [6, 22-25].

2.2 Engaging with food's materiality for dynamic presentations in contemporary gastronomy

We find that practitioners in contemporary gastronomy have been engaging with food's materiality for the innovation of new cuisines to enrich dining experiences. Specifically, chefs have developed "animated" food that changes its original state on the plate (e.g., shape, color) to create "magical" food experiences [74]. For example, the dessert "Flor de Cacao" [35] represents a cocoa bean that opens up like a cacao flower through contact with hot chocolate sauce. Similarly, mixologists have shown a growing interest in producing color-changing cocktails. One prominent example is a cocktail with a pH-sensitive ingredient (butterfly pea flower tea) that can instantly change from blue to violet when blended with citric drinks [70]. Such state changes in food realize a "dynamic presentation" to please the diners. However, while culinary techniques like these can often facilitate a pleasurable dining experience, they offer only one fixed way of enjoying the food/drink once it has been produced. Such "one-off" experiences mean that the dining process is predominantly pre-set by the food creator (i.e., the chef), and, consequently, there is little room for "inter-actions" [89] between the diners and the food.

In response to this, we intend to explore the possibility of employing food's material qualities to realize computational food in a more temporal way. In particular, we aim to use food's physical process for the direct realization of a computational process (e.g., take in information, perform logical operations, sense, and react [71]), and simultaneously, use computational capabilities to achieve desired operations and effects (e.g., shape/color changes) that can dynamically change over time.

2.3 Learning from computational matters to achieve transformative qualities

Many forms of matter have complex structures and dynamics that can be regarded as a computational system, relating certain computational properties and powers to the material substrate's physical properties [75]. Prior research explored various ways to program highly deformable materials that can respond to various external stimuli, including using synergetic chemical and physical programming for reversible shape-shifting actuators [52, 72] and biohybrid materials in a smart wearable that can reversibly change its shape in response to body temperature and humidity [92]. Furthermore, researchers have experimented with the programmability of food materials, including the encoding of active structures into food materials, which enables the food to transform physically in response to external stimuli [42, 86]. These examples show that there are a variety of possibilities to encode computational capabilities, such as actuation or sensing, into certain materials. Nevertheless, the design of dynamic trajectories enabled by the computational power is still underexplored.

We took inspiration from prior research on "material integration" [22] that introduced the notion of "food as computational artifact". Specifically, the authors designed a dessert that can realize the basic building blocks of computation – the three basic logic gates (AND, OR, and XOR) – and "compute" its own flavor [25]. Moving beyond this work, in this paper, we aim to extend the view of computational food away from the design of a "thing" with limited transitions, toward the design of food as "events" involving dynamic changes [90].

Taken together, our review of prior work yielded three major insights: i) existing HFI approaches appear to have missed opportunities to engage with the affordances of food; ii) culinary practices have already embraced the opportunity to engage with dynamic food using its material affordances; iii) and, although research has begun to explore food as computational material, prior work has so far focused on limited physical transitions and missed opportunities for reconfigurations via dynamic trajectories. In response, in this paper, we attempt to answer the research question: *How do we design computational food for dynamic trajectories?*

3 METHODOLOGY

We explored the dynamic trajectories within computational food through a combination of "Research through Design" (RtD) [94, 95] and "material speculation" [85]. In RtD, the design of a novel artifact, as a reflective practice, is a source of new knowledge that is "topical, procedural, pragmatic and conceptual" [31]. In this way, we see our design not as a final product but as a "material speculation" [85] within the RtD tradition. We aim to exploit Dancing Delicacies to provoke possible world accounts which extend the inquiry beyond the system itself. In other words, we see our design as a proposition "being at the boundary of the actual and the possible", to encourage speculation and inspire possible HFI futures [28, 85].

In undertaking this exploration, we recognize that RtD is not a singular research method or approach, rather, it is "a multitude of legitimate intersections" between design practice and research [57]. Specifically, in this paper, our RtD exploration has four facets. Firstly, we documented our prototyping process of "Dancing Delicacies" system. This process was a means of inquiry (i.e., experimentation and reflection) into new ways of making and interacting with computational food. Secondly, our designed system serves the purpose of a "research archetype" [57], that is, a "physical embodiment" of a new design space [57] corresponding to our proposed conception of computational food. It concretizes our latter concept of shifting relationships within novel creator-food-consumer interactions enabled by dynamic trajectories with computational food. Thirdly, we identify the key dimensions within a framework to illustrate the richness of the emerging design directions of dynamic trajectories with computational food. Also, by demonstrating four exemplar Dancing Delicacies dishes as "narrative proposals" [32] and positioning them within our framework, we intended to explicate different design directions concerning future design possibilities. Finally, through a preliminary engagement with expert practitioners from the hospitality industry, we leverage our designs to provoke insights into speculative use contexts.

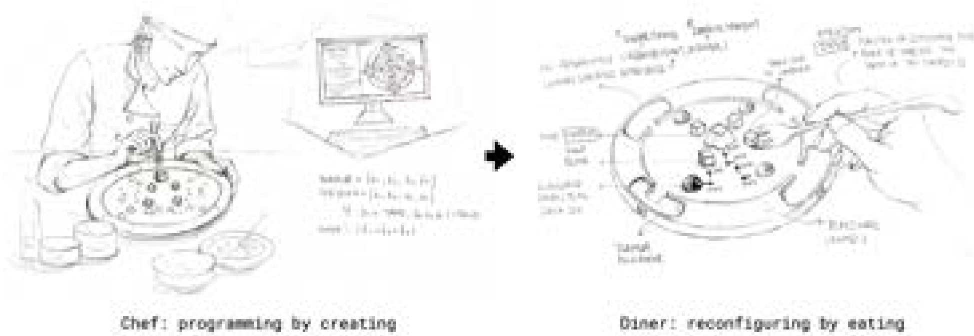

Figure 2: Concept sketches of Dancing Delicacies.

4 DESIGN PROCESS

4.1 Exploiting electrowetting technology for computational food design

Taking inspiration from the notion of "unconventional computing", which is grounded in the intention to conceive "other ways to compute" [3], we note that a computer can take alternative forms, such as computers made of liquids [2]. Liquids, especially in the form of water droplets, are particularly versatile computational materials [43] that can be manipulated and programmed with evaporative [17], optical [9], acoustic [67], magnetic [53], and electric forces on a surface [33] and in a dielectric fluid [38]. Also, it is important to note that liquids, such as soup, broth, coulis, liquor, and syrup, are essential elements in culinary practices, not only for gustatory enjoyment but also for the overall sense of aesthetic delight in eating experiences.

In particular, our design was inspired by prior research that exploited "electrowetting on dielectric (EWOD)" technology [15, 56, 79, 80, 93] to achieve precise motion operations of aqueous droplets, and used them as an interaction medium without altering their material composition [80]. EWOD technology utilizes electrical voltage to unbalance the force equilibrium at the solid-liquid-vapor interface, causing the droplets to move toward the charged electrodes [5]. Previously, EWOD systems have been used mostly in biological and medical experiments, such as for DNA extraction [4], and drug delivery [64]. Other applications used EWOD technology for optical imaging [36], power energy harvesting [49], and very rarely, food analyzing and testing [12], but not for culinary purposes. Furthermore, prior work suggested a set of strategies for droplet operations with a non-food EWOD system, including "moving", "dispensing", "merging", and "mixing" [78, 80]. We draw from this prior knowledge around EWOD and extend it to food experiences to realize our design. Our design concept (Figure 2) is a dish on a plate containing different food items and ingredients; some food items are in the form of aqueous droplets that can be manipulated using EWOD technology embedded in the plate. A chef can "program" the dish during the process of its creation and choreograph the diner's encounters within the dining trajectories. Based on how the dish has been programmed, the diner can "reconfigure" it to enjoy different eating trajectories.

We found that most existing EWOD systems used a fixed form with micro-sized electrodes. This means that the systems can only handle small volumes of liquids, which makes it challenging to serve a sufficient portion of a proper dish. Furthermore, although a few systems worked with foodstuff, they were not specifically designed for authentic dishes in a dining context. Therefore, in our design, we first increased the size of a single electrode from the traditional millimeter scale to a centimeter scale (1cm*1cm), enabling the effective manipulation of a droplet from 215μL to 430μL. We then arranged the electrode array into a particular shape and embedded the electrode board into a 3D-printed plateware as the container of food droplets. We detail our prototyping process next.

4.2 Prototyping the Dancing Delicacies system

Our final design of the plateware has three major components: an electrode board, a dielectric film surface that is held by a frame, and a 3D-printed plate with two assembling parts (top and base) (Figure 3). Our design iteration process was primarily guided by the following constraints and considerations:

- Technical constraints. We intended to utilize the OpenDrop V4 controller [5] to realize our design. Therefore, we were constrained by the maximum number of electrodes the controller can support: 128.
- Utilitarian considerations: We arranged the electrodes in a circular shape to ensure the overall size of the plateware is in line with regular dish plates (∅:230mm) while zoning the plateware into two different functional divisions (Figure 3).

The fabrication process included customizing the electrode board, making a dielectric surface, and designing a plateware. This was followed by combining all components into a visually pleasing design.

We created an electrode board by manufacturing a multi-layer printed circuit board (PCB). The electrode board comprises of a silver-coated 128 electrodes array with each individually 10 mm x 10 mm in size and 0.127mm gaps between electrodes (Figure 4a-b). There are also two HV507 drivers underneath the board (Figure 4c). The electrode board interfaces with a controller to realize droplet manipulation. The successful movement of a droplet from one electrode to another depends upon the reversible polarization of

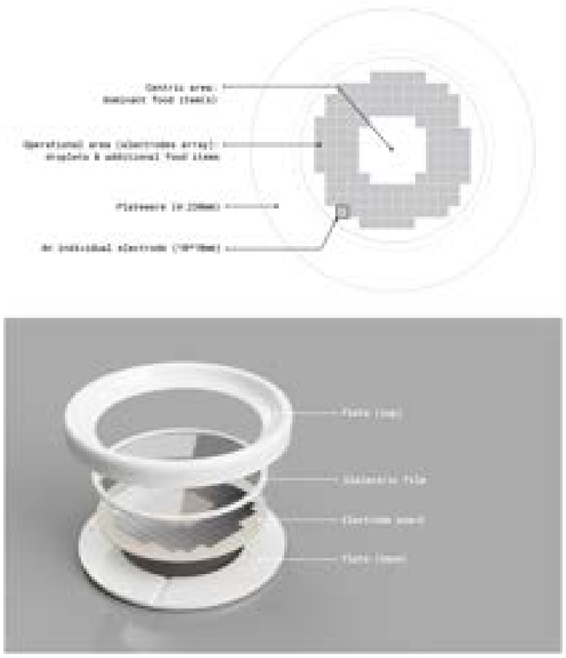

Figure 3: Functional divisions (top) and schematic structure (bottom) of the plateware.

Figure 4: a) A printed circuit board holds the electrode array; b-c) The individual electrodes are connected to the backside of the circuit board through vertical interconnects and linked to a connector on the back with 128 channels.

a surface made of a thin dielectric film, which sits on top of the electrode board. The performance of EWOD is highly dependent on the thickness and surface energy of the dielectric film [5, 78, 80], and we have used "Parafilm®M laboratory film" as recommended [5, 78]. The electrode board and dielectric film were assembled within a 3-D printed plate and connected to an OpenDrop V4 controller that operates at 240V DC and 1000Hz via an FFC cable (Figure 6). Note that the dielectric film electrically insulates the electrode board and the charge on the electrodes from the system delivered to a diner is minimal [78].

4.3 Engaging with food materials

We identified a library of food materials that can best engage with the system (Figure 7). Note that this library is not exhaustive; it represents the results of an initial investigation of readily available food materials with different properties.

Figure 5: a) Fabricating the electrode board; b) Making a dielectric film surface held by a 3D-printed frame; c) 3D-printing a plate case.

Prior work with non-food droplets [56] demonstrated that the hysteresis of a droplet (which causes some drops to stick on the surface) has been one of the shortcomings of EWOD technology. There has been limited exploration of the various properties of foods and beverages that might cause hysteresis when using EWOD technology. We hence began with off-the-shelf aqueous food materials including water, tea, vinegar, soda, milk, liquor, coffee, and wine which we determined could make suitable operational droplets (i.e., the system could manipulate their movements). We found that a liquid's viscosity might increase the probability of droplet hysteresis, confirming prior work on non-food droplets [56]. This result could be due to the viscous damping of the surface capillary waves, which leads to an increased inertial wetting time [16]. We also experimented with solid, soluble, and insoluble food items, such as small pieces of bread, herbs, tea leaves, instant coffee, and Vitamin C effervescent tablets. We found that these food items can be used to alter the operational droplets' flavors and their states by soaking, infusing, and dissolving them in the droplets. It is worth noting that the buoyancy of a solid item (whether the item can be transported by a droplet) is determined by multiphysics (e.g., density, wettability, aspect ratio, etc.). Lastly, inspired by molecular gastronomy, we also found that compounds, such as sodium alginate, calcium chloride, gelatin, and agar-agar, could be added to the droplets to change their properties through physical and chemical reactions.

4.4 Fundamental droplet operations

We offer a "visual interface" as a design tool for programming food. This tool is built upon the original work by OpenDrop and offers a simple and visual way allowing food creators, such as chefs, to manipulate the food droplets' movements in real-time. Through controlling electrode on/off states frame by frame, chefs can realize desired operations of food items and choreograph various dining trajectories that the diners would encounter (Figure 8).

We explored a set of fundamental droplet operations by using the visual interface. Inspired by prior works with a non-food EWOD system [78, 80], we identified eight fundamental droplet operations that our system makes possible, and we categorized them into four levels according to complexity (Figure 9).

The base level (lowest complexity) encompasses two basic "move" operations: travel and merge. Travel refers to one or multiple droplets changing their original location, moving from one cell to another following a predefined path. The maximum droplet (volume=200μL) velocity with our system was 17.5mm/s. Merge refers to two or more droplets moving toward each other and meeting at the same electrode.

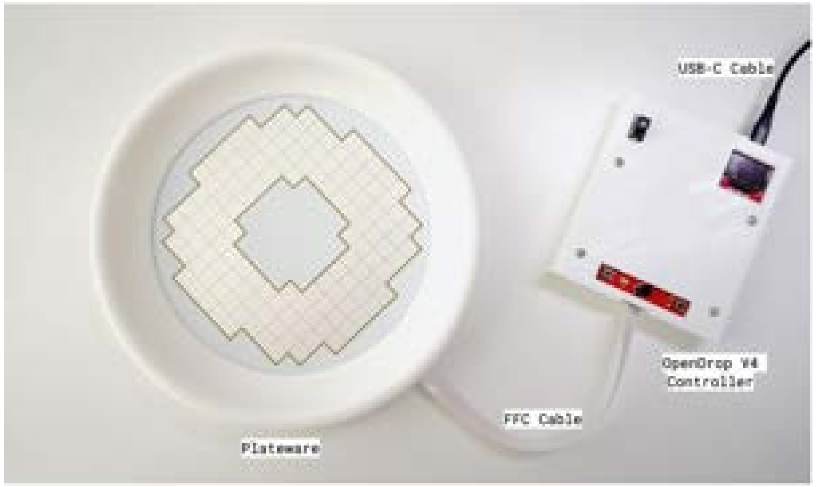

Figure 6: A complete Dancing Delicacies system consists of a plateware with an embedded electrode board connected to an OpenDrop V4 controller via an FFC cable, and a USB-C cable for communication and powering.

Figure 7: Food materials and their utility.

Level one, building on the base level, encompasses two more complex operations: oscillate and blend. Oscillate means a droplet keeps moving from one electrode to another and back again at regular temporal intervals. For example, a droplet keeps moving back and forth between points A and B. Blend refers to two or more droplets meeting at some point and blending into a mixture. For example, two droplets meet and circle from point A to B to C to D and back to A to blend with each other until evenly mixed.

Level two encompasses operations that involve extra (solid) food items apart from droplets: delivery, and transport. Delivery is concerned with one or more droplets carrying additional food items to a certain destination. For example, in our test, a droplet carries a dried basil leaf fragment from point A to destination B (distance=60mm, time=9s). At destination B, the droplet "drops" the leaf as the droplet is soaked up by, for example, a piece of bread. Transport refers to a droplet carrying additional food items moving around the plate.

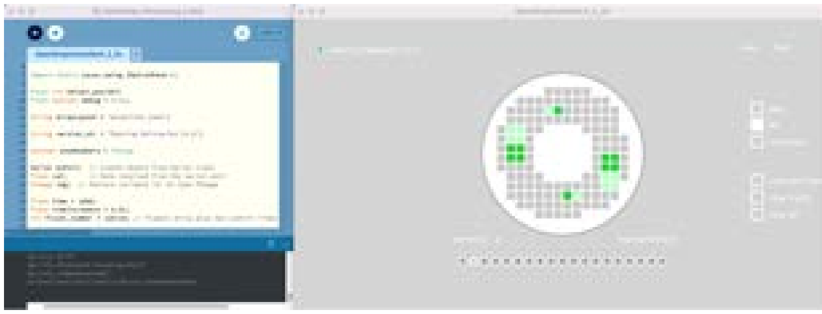

Figure 8: The visual interface for programming food.

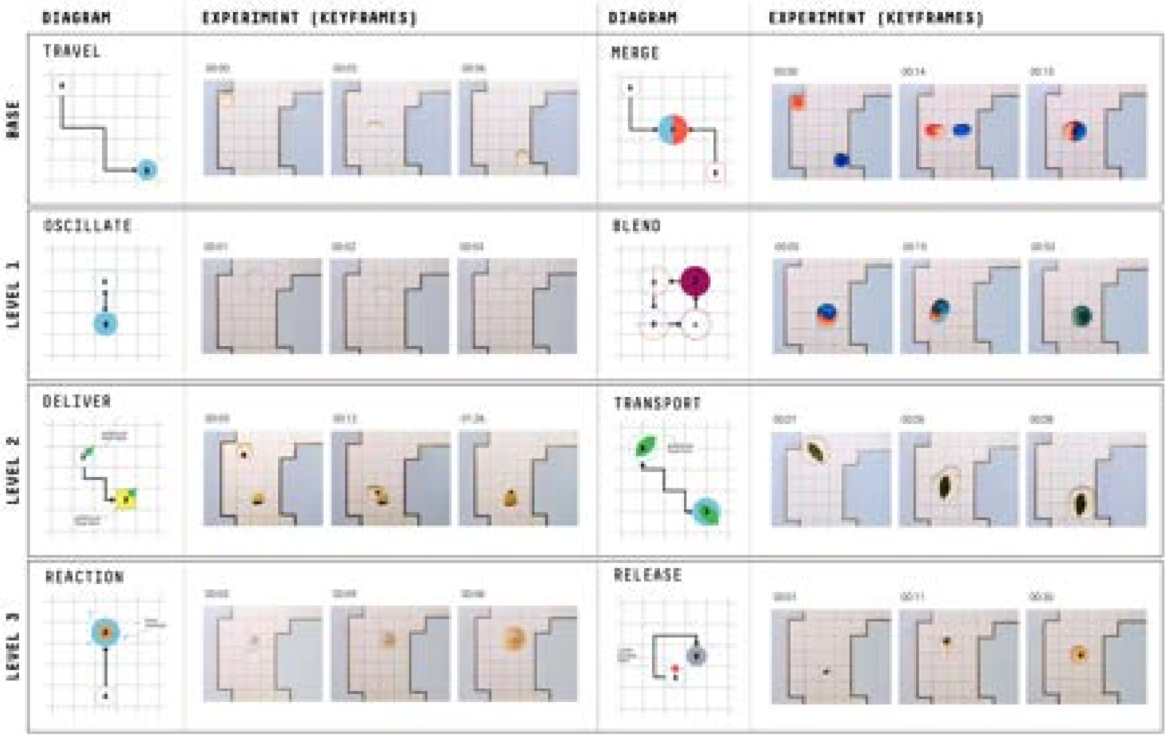

Figure 9: Fundamental droplet operations.

For example, a droplet carries a leaf while moving along a predefined pathway. This operation could be useful in situations when food items should be moved, but the movement is not supported by the underlying technology (i.e., leaves do not respond to the EWOD technology). To transport larger items, we could increase the volume and hence enlarge the cargo capacity of the droplet.

Level three considers additional consequences caused by the base operations: reaction and release. Reaction refers to droplets moving so that they physically or chemically react with other items. For example, if a droplet meets an effervescent tablet, it begins to bubble up. Release means that the water-soluble item gradually dissolves in the droplet while it is moving around. For example, a piece of freeze-dried instant coffee is slowly released into a droplet.

4.5 Possible interactions with Dancing Delicacies

Next, we describe possible interactions with Dancing Delicacies. We were inspired by prior non-food EWOD work that identified various ways of moving droplets, including directly touching the droplets, tilting the interaction surface, blowing onto the droplets, and manually adding and removing the droplets using pipettes or wiping them off [78, 80]. Building on this, we identified three approaches: direct manipulation, time-based interaction, and sensing.

“Direct manipulation”, inspired by the general HCI term, refers to the diner changing the droplet’s movements through physical actions. For example, the diner could use a fingertip or cutlery to drag the droplet to a desired location; add food items onto or remove them from electrodes to block or unblock the path of a moving droplet; blow onto droplets; or tilt the plate to change the direction of the droplets' movement. While direct manipulation could potentially encourage a close personal engagement, it only allows the diner to act on one droplet or a small number of adjacent droplets at a time. This approach could also cause accidental activations (e.g., droplet collision and unintended interactions).

"Time-based interaction" refers to exploiting "time" as a design source for interactions with Dancing Delicacies to coordinate multiple operations in real-time. For example, a diner might need to wait for a droplet's movement to be carried out within a pre-programmed amount of time before they can carry out a new action. Time-based interaction allows for synchronization between diners' actions and computational operations (directed by the food creator).

Lastly, while we have not yet implemented it in our system, the capability of sensing has been explored with EWOD devices [40, 54], using embedded capacitive sensing units to realize the detection and reading of droplets' locations and movements, and to recognize the presence of other food items (mostly conductive), and to process any feedback obtained. Based on this understanding, we propose possible dish designs that might exploit this approach (section 5.3).

5 DESIGN SPACE

We developed a two-dimensional framework illustrating an emerging design space of computational food with dynamic trajectories. The framework saves as a conceptual constraint that can be utilized by designers to reflect on the distinctiveness between different designs. It might also help designers identify underexplored areas, highlighting opportunities for future investigations. In this section, we first articulate the two dimensions within our design space (5.1); then we present four design directions emerging from the four quadrants, demonstrated through four design exemplars of Dancing Delicacies dishes (5.2); lastly, we discuss the implications of dynamic trajectories for HFI through a reflection on the designed exemplar dishes (5.3).

5.1 Two dimensions

We identified two dimensions that designers might take into consideration when aiming to design dynamic trajectories within computational food (Figure 10): "level of the diner's control over the dish's computational processes", and "gastronomic value". The first dimension was derived from the inherent shifting of control derived through the interactions with the food facilitated by computational processes that we identified through our design practice, as suggested in prior work [27]. The second dimension was inspired by prior findings that design intentions can be directed by sensations and perceptions – where interaction designers can either focus on technology that provides "localized sensations" (e.g., tactility and taste) or "perceptions outside of myself" (e.g., vision) [60] – here, we have identified two ends through our design practice that point at two distinct design intentions: "gustatory-focused" (taste stimuli) and "aesthetic-focused" (visual stimuli).

The first dimension, plotted on the horizontal axis, indicates the level of the diner's control over the dish's computational process when eating, ranging from a low to a high level. A low level of control means that the dish affords fewer parameters for diners to control the dish's computation. This could provide sufficient guidance to lead diners into predefined trajectories to enjoy the dish. In contrast, a high level of control means that the diner has more parameters to control the dish. Higher levels of control are usually implemented to give the diner more agency to personalize their dish and explore unknown flavor experiences.

The second dimension, plotted on the vertical axis, denotes the gastronomic value of a dish as aimed for by the food creator through the computational process. Gustatory-focused refers to a design intention that is more inclined to focus on the transitioning of a dish's tastes and textures (mouthfeel) that provides diners with palatable "localized sensations". Aesthetic-focused refers to a design intention that is more inclined to focus on the transitioning of a dish's visual appearances and movements that provides diners with varying "outside of myself" perceptions. Note that although food creators could aim to balance a dish's palatability and visual presentation, we find that there often appears to be a compromise that they need to make (usually due to technical limitations). We now describe four quadrants that result from the two dimensions, which help to explain the different options food creators have.

5.2 Design directions with exemplar Dancing Delicacies dishes

The dimensions form four quadrants that allow us to articulate four design directions: "instructional", "directional", "performative" and "freeform" (Figure 10). We hope that these design directions could benefit food creators by providing a starting point on which to orient their decisions, establish their design goals, as well as envisage the possible outcomes. We articulate each quadrant through our design of four exemplar Dancing Delicacies dishes. These exemplar dishes serve as "narrative proposals" which remain "open to imaginary extensions, developments, and modifications" for future design possibilities [32]. As such, the dish designs are "placeholders" [32], occupying each direction in the design space without necessarily being the perfect designs to populate it.

5.2.1 Instructional dish: Jelly Wagashi. The dish "Jelly Wagashi" is situated in the upper left quadrant which is more gustatory-focused, and diners have a low level of control over the computation. It facilitates an instructional trajectory of eating through engaging with a certain recipe and dining process that was predefined by the food creator. Diners mostly follow the lead provided by the dish based on the food creator's programming. The plate is divided into four different functional areas (Figure 11). While the dish follows a predefined series of steps to prepare the meal as the droplet moves through different areas, the diner is given the option to nudge flavorings or additional ingredients to the droplet to alter its flavor.

There are five steps to enjoy the Jelly Wagashi dish. These are shown in the flowchart, with five keyframes (referred to as "KF") (Figure 15). When the dish is served, the diner is presented with a flavoring droplet oscillating in the synthesizer area, suggesting that the diner uses their cutlery (here, a small spoon) to drive a base droplet toward it and wait until the two droplets are fully mixed (KF2). Next, the mixed droplet travels toward the solid food item repository. It stops for 5 seconds in front of each of the solid food items to allow the diner to put one or multiple solid food items onto the droplet (KF3). Then, the droplet, carrying the food item(s), moves toward the beverage synthesizer area, where it blends with

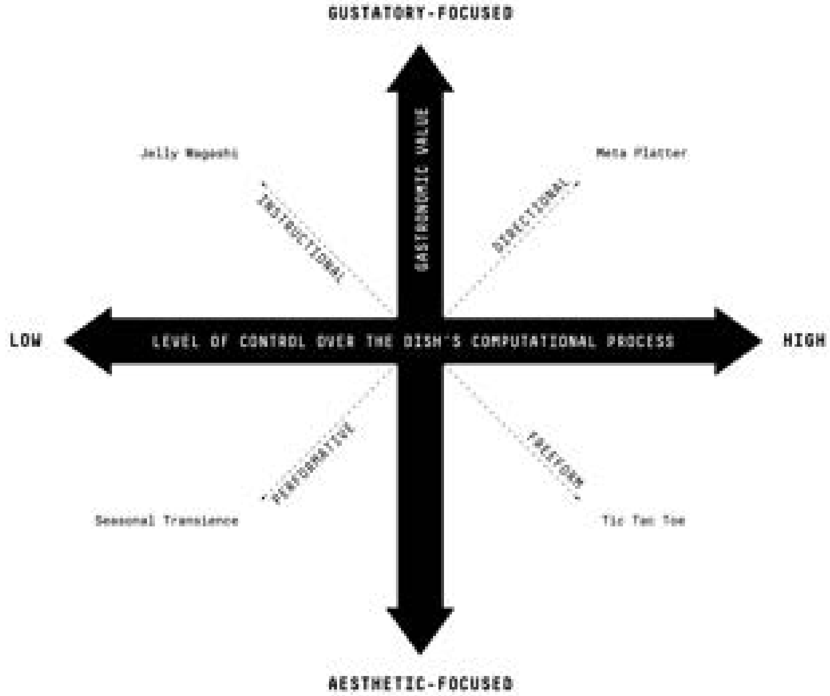

Figure 10: Design space of dynamic trajectories within computational food.

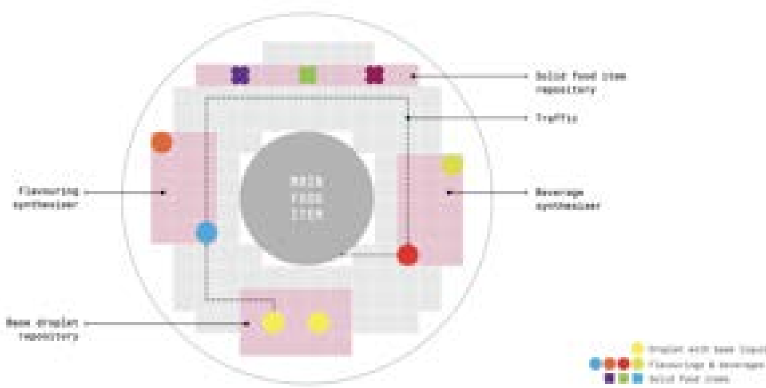

Figure 11: Initial plating of Jelly Wagashi.

a beverage droplet via the circling "blend" operation (KF4). Once the droplet is fully mixed after five rounds of circling, it travels to the main food item, the plain jelly cake, which soaks up the droplet (KF5) and becomes flavorful and ready for consumption.

5.2.2 *Directional dish 2: Meta Platter.* The "Meta Platter" dish sits in the upper-right quadrant, it is gustatory-focused, and gives diners a high level of control over the dish's computation. This dish offers a decision-based eating trajectory where the diner keeps coming to decision points and must choose between options. Each choice alters the droplet's trajectory and leads the diner down a different path toward one of many possible outcomes (Figure 14). Based on the diner's choices, the controller acknowledges user input through its sensing functions, then proceeds and moves the droplet down the corresponding path until the droplet meets the next decision point or a termination condition. As a result, food preparation and its possible outcomes are represented with a decision tree, where each node is a decision point, and the terminal nodes symbolize the possible food outcomes. In our design, there are four different branching trajectories that a diner would encounter. Note this dish involves "sensing", where we leave the implementation for future research. In this paper, we simply demonstrate the snapshots using the visual user interface (Figure 16).

Figure 15 shows the flow of one probable trajectory that a diner could go through. The diner encounters the first branch at decision

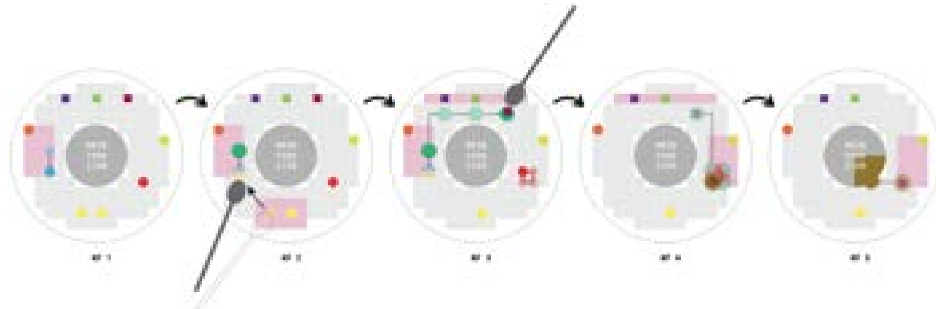

Figure 12: Flow chart of interacting with Jelly Wagashi.

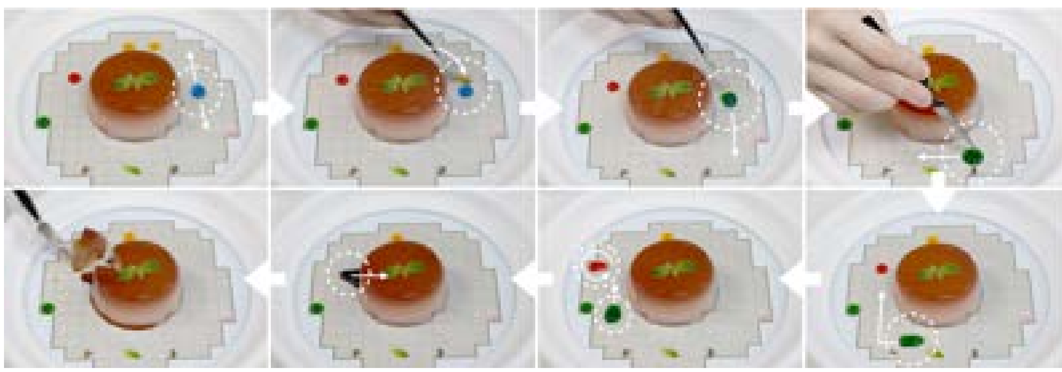

Figure 13: Demonstration of Jelly Wagashi in action. Our recipe: 1) Jelly cake (main food item): gelling powder (carrageenan), raspberry jam, sugar; 2) Droplets in operation (dyed with food colors): lemon juice (yellow), honey drink (blue), strawberry juice (red); 3) Solid food items: green tea, mint leaf, coffee grains.

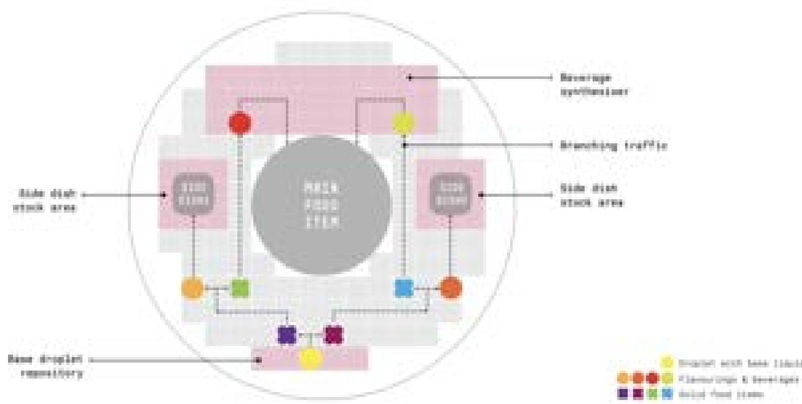

Figure 14: Initial plating of the Meta Platter with a branching traffic map with four different trajectories depending on the diner's choices.

point 1, where they must decide to nudge the base droplet toward food item A or B. Assuming that the diner selects A, a mixture of C as outcome 1 is generated, which moves toward decision point 2. Again, the diner needs to choose between the solid food items D or E. If the diner selects E, the mixture C combines with E, producing F as outcome 2. Finally, the result is blended with a beverage droplet in the beverage synthesizer, then soaked up by the main food item, resulting in the final outcome that is ready for consumption.

5.2.3 Performative dish 3: Seasonal Transience. The performative dish "Seasonal Transience" sits in the lower-left quadrant, and it is more concerned with the dish's presentation (and less with how it tastes). Dishes in this quadrant often afford a low level

Figure 15: Flow chart of interacting with Meta Platter.

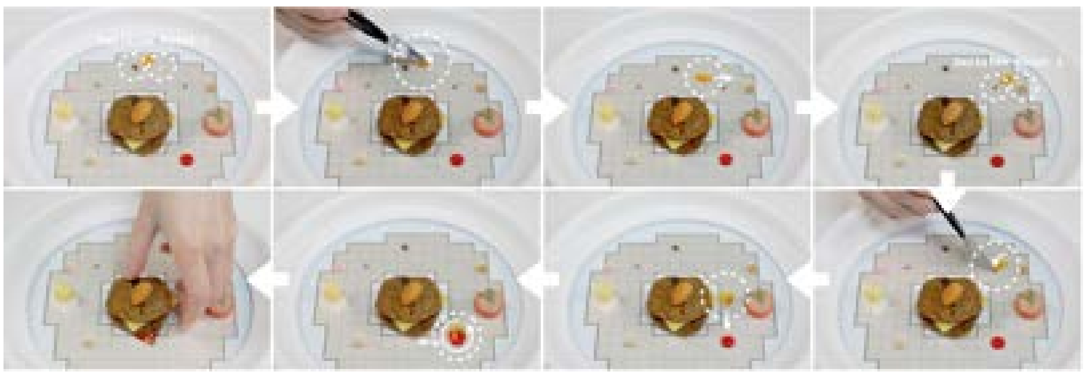

Figure 16: Demonstration of Meta Platter in action. Our recipe: 1) Main food item: aged cheddar, artisan crackers, almond; 2) Optional droplets (some of them were dyed with food colors): lemon juice (yellow), vinegar (brown), strawberry juice (red), tea (light yellow), grapefruit juice (pink); 3) Solid food items: cabanossi with rosemary, cheese with coconut flakes, coffee grains, dried basil leaves, green tea leaves.

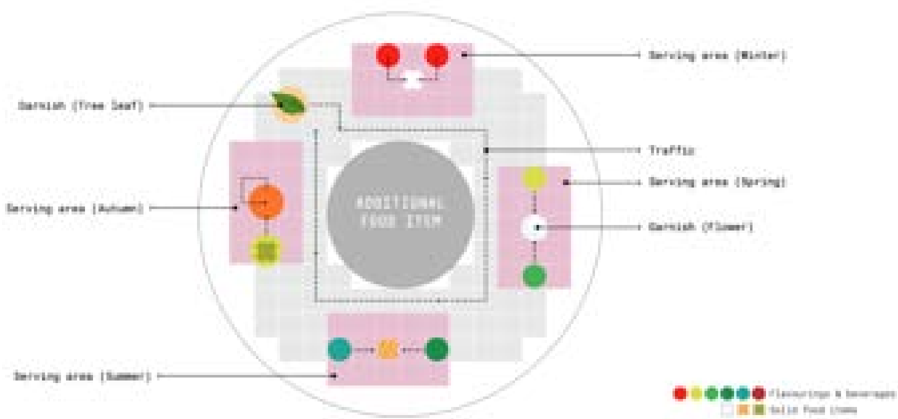

Figure 17: Initial plating of Seasonal Transience.

of control over the computation while focusing on the aesthetics that highlights the visual appeal and expressiveness of a dish. The Seasonal Transience dish was inspired by Japanese sweets that reflect the changing seasons [1, 30]. Using the plate as a stage to present a performance, diners could step into an edible story with four different trajectories that transform with the seasons. The plate is divided into four areas for serving different foods representing each season. Each area is populated with droplets and additional food items as props. A mint leaf is carried on a droplet and moves through the areas (seasons), indicating the flow of the performance (Figure 17). As the leaf moves toward an area, it triggers the corresponding executions in each area simultaneously.

The trajectory starts with the migratory mint leaf moving toward the winter season (Figure 18), and simultaneously, two droplets of flavoring (e.g., warm strawberry juice) move toward each other and then mix with the food items (yogurt sorbet) in the winter area (a). When the sorbet starts to melt, representing melting snow in winter, diners can start to enjoy the first course in the winter.

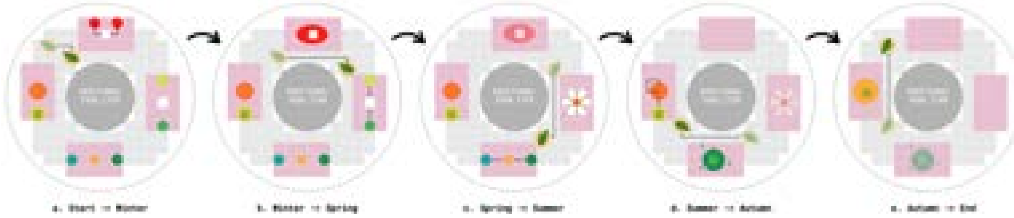

Figure 18: Flow chart of interacting with Seasonal Transience.

Figure 19: Demonstration of Seasonal Transience in action. Our recipe: 1) Additional food item (center) and garnishes: rice cracker, rice paper cutout (flower), mint leaf; 2) Winter: strawberry juice (red), frozen yogurt; 2) Spring: green juice, flower garnish (rice paper), goji berry; 3) Summer: tropical fruit juice, effervescent tablet (lemon); 4) Autumn: jasmine tea, orange juice.

After five minutes, the mint leaf begins to move again, toward the spring area. At the same time, two droplets in the area start to move toward a "bud" (a flower garnish made of rice paper) (b). The bud is soaked by the droplets and begins to open into a flower, representing the spring bloom. Diners can now start to enjoy the second course in the spring (c). Next, the mint leaf moves toward the summer after 5 minutes while two droplets move toward a food item (e.g., a small piece of effervescent fruit tablet) in the summer area. The tablet quickly reacts to the droplets, producing a fizzing sound that mimics rainfall in the lush green summer (d). Finally, the mint leaf's trip ends at its last stop, the autumn. Two droplets blend into a golden yellow color, representing a golden autumn (e).

5.2.4 Freeform dish: Tic Tac Toe. The "Tic Tac Toe" dish sits in the lower-right quadrant. Dishes in this quadrant facilitate a high level of control over the computation, and their design tends to be dominated by aesthetic considerations. Here, we propose an edible game which is divided into a droplet repository and a 3-by-3 grid playground. It is programmed to play a tic tac toe game with the diner. The playground is diagonally oriented to avoid droplet adjacency. The droplet's behaviors (i.e., rules and droplet paths) can be directly programmed into the controller via an Arduino script [31], and the antagonistic moves are generated based on the state of the board (Figure 20). As this dish involves using sensing and the path-planning algorithm to process feedback obtained from the presence of food items and avoid droplet collision, we leave the implementation of the dish for future research. In this paper, we demonstrate the snapshots of each move in the game using the visual user interface.

During the game, the diner will be served extra food items ("crosses") besides the dish. When the diner places a food item on the grid, the system detects its position, determines the placement of an antagonistic droplet next, and moves a droplet (as a "naught") to the computed placement to complete its move. Note that an existing droplet on the playground might need to move away from its original cell to make room for the next droplet to move through to the targeting cell to avoid two droplets collide (Figure 21 - 4th Move). Whoever (the diner or the system) succeeds in placing three of their marks in a horizontal, vertical, or diagonal row (the diner or the system) is the winner. If the diner loses the game or the game ends in a tie, the diner consumes all the food items in the "playground"; while if the diner wins, they get the chance to eat the main food item at the center as a reward.

5.3 Implications of dynamic trajectories within Dancing Delicacies dishes

Through a reflection on each of our exemplar dishes, we discuss the implications of dynamic trajectories within designing Dancing Delicacies dishes to provide an initial understanding of what they could mean for future HFI design.

The **instructional** trajectory facilitated by the "Jelly Wagashi" dish provided a dining experience akin to "live-cooking" (as often the case in some fine dining restaurants where chefs cook in front of the guests) but without chefs standing by. The chef would only need

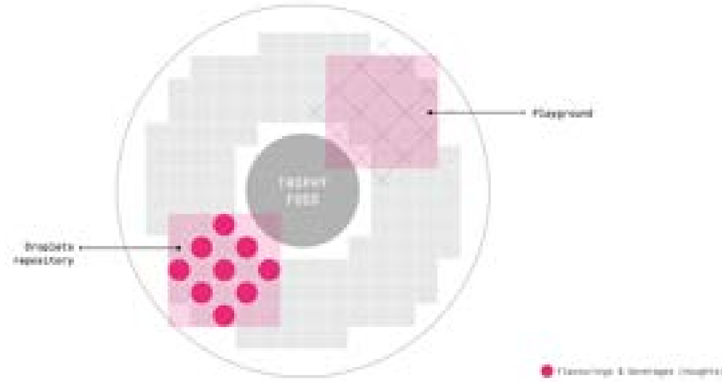

Figure 20: Initial plating of Tic Tac Toe.

Figure 21: Flow chart of moves resulting in one possible board position when the diner makes the first move.

Figure 22: Demonstration of Tic Tac Toe in action. Our recipe: 1) Reward food: chicken nuggets, sour cream, celery; 2) Naughts: grapefruit juice; 3) Crosses: green peas.

to supply selected ingredients and food items on the plate, while the system would lead the diners to enjoy the dish according to the pre-programmed path curated by the chef. While the diner is given some level of customizability (i.e., pick a food item), the diner's actions do not affect the trajectory. Hence the system ensures a consistent quality of the dish. An instructional trajectory would especially benefit diners who desire an optimized flavor experience by relying on the food creator to ensure a palatable outcome. The chef can fully demonstrate their skill and expertise, and, at the same time, the diner will not be overwhelmed by dazzling choices.

The **directional** trajectory in the "Meta Platter" dish carries out a selection and decision-based recipe, and both the diner and creator are given joint control over the dining trajectory. The diner is provided with a collection of ingredients that they can pick as they like. Yet, unlike Jelly Wagashi, which is guaranteed to produce a dish based on a given recipe and a defined trajectory, here, the decisions the diner makes may lead to a different result. In other words, the dish is centered around the diner's decisions, and the chef is responsible for programming the conditions and options (i.e., the nodes of the decision tree) to produce a palatable outcome. Such a directional trajectory implies a synergy between the dish creator and the diner. The resulting dish design might be more suitable for diners who are eager to explore novel taste experiences and appreciate the opportunity to experiment with food.

With the **performative** trajectory, we demonstrate that food can enact key roles in a performance to convey stories. We note that using food as a display and representation of information has become increasingly popular in HFI [45-48, 62]. Existing works often use arranged food items to display information, such as arrays of bubbles [39] or dyed/clear water in perfusable channels to show patterns or digits [91]. Instead of simply arranging the food to visualize information, we regard food as a computational agent that interacts with the inter-material properties in a performative manner. This perspective speaks to prior work, which acknowledged that food and performance share "the same theatrical conventions precisely because they were both threads in the complex design of regal hospitality" [18]. Seasonal Transience offers a new way for diners to appreciate the artistry of a performance composed by chefs and presents a new form of storytelling that can be facilitated dynamically by the dish itself. In addition to the dish's artistic and narrative values, the food's movements can also be leveraged to steer the diner's attention or promote certain dining behaviors. For example, if the diner becomes distracted from the dish, the food on the plate could start to move to regain the user's attention.

The **freeform** trajectory facilitated by the "Tic Tac Toe" dish used food as both input and output, in contrast with the existing food-as-display research [62]. In particular, the droplet's actions are not choreographed but instead generated by an algorithm, thereby possibly making them adaptive to the context. From the diner's perspective, the droplets may also present an illusion of being "smart" while retaining their authentic food properties, making dining a fun and interactive experience while the food remains palatable. Moreover, we envision that our system could enable the droplets to respond to the user's actions differently depending on the context and pre-programmed rules. We speculate that techniques like this may help to promote desirable eating behaviors, such as using games to retain children's attention while dining and promoting a balanced diet by using digital play to incentivize eating vegetables [55]. We present this implementation as an exploration of using computational food as an interactive media, and the application of such systems presents a future design opportunity for "playful HFI" [7, 61].

6 PRELIMINARY ENGAGEMENT WITH EXPERT PRACTITIONERS

We engaged with a variety of expert practitioners by organizing an "interactive food" event and conducting expert interviews followed by the event. Our event attracted a number of expert practitioners (60 attendees) from the hospitality industry, including chefs, food producers, retailers, journalists, and food technology engineers, as well as academics with an interest in interactive food. Organizing this event allowed us to bring our design into the real-world for communication among disparate stakeholders, and to gain an initial understanding of their first impressions of, and their overall attitudes and opinions toward our design. The event consisted of five sections: an "interactivity"-style demonstration (60mins) that sandwiched introductory and "interactive food" panel talks (45mins), followed by socializing (30mins). In the demonstration session, attendees were able to engage with our Dancing Delicacies system, with the help of one researcher who provided instructions and two researchers who assisted with programming the dish via our visual interface to manipulate the food droplets' movements. Attendees were given the option to participate in follow-up interviews in a more private setting to further elaborate on their thoughts and further unpack their insights into their interactivity experience.

Five participants (range 25–48 years, M=32.40, S.D.=9.02) who all had at least 5-year industry experience, volunteered for the follow-up interviews. The semi-structured interviews were conducted online after the event, lasted 45-60 minutes, and were audio/video recorded with the participants' consent. During the interviews, we firstly asked participants to identify and describe their preferred role in daily food practices and their experiences with food-related digital technology. This provided us with first-person insights into how participants perceived themselves as a "foodie" who has an ardent or refined interest in cooking or eating food and their experiences with using digital technology around food practices. These responses helped us to put participants' insights collected through the interviews into the context of our research focus (Table 1). Next, based on what the participants saw and experienced at the event, we asked several probing questions to establish a basis for open conversations to gain insights into how experts perceive the potential values of dynamic trajectories with computational food and speculate possible use contexts.

6.1 Findings

The interviews were transcribed and analyzed using a reflexive thematic analysis approach [14]. We used open coding to uncover prevalent themes among the participants' descriptions of their experiences and speculations of use context. Our analysis resulted in a final set of 52 codes, which we then examined for recurring themes. Our findings encapsulate seven emerging themes and suggested a strong interest and enjoyment among participants when interacting with the system.

6.1.1 Theme 1: Dynamic emotion evocations in savoring the art. All participants suggested that the Dancing Delicacies design has the potential to offer novel dining experiences through adding a "'wow' factor" to "amaze the diners" (Kath). Specifically, in response to the dynamic movements and the "aesthetic" quality of the performative dish, Luke highlighted the concept of "emotional evocation" of food products that would allow diners to "experiment with the rhythm and contexts of the dancing based on their mood". For example, diners could create a "slow" or "fast dance", with a "different cultural type", like a "beautiful, almost, like, an artistic experience" in a fine dining context. Gabe stressed this by pointing out that "food is not just a taste experience, it's visual, it's emotional, it comes as many aspects of being a human person". This theme extended our reflection on the implications of a "performative" trajectory and suggested the potential to evoke emotions when savoring the dish as an artwork.

6.1.2 Theme 2: Playfulness for family-friendly engagement. Participants mentioned that the system provided "a playful way to rethink the experience [of eating]" (Luke). Luke added that the system could "create a fun exercise where it's playful and the kids could program the dessert and it brings together different flavors, as children are much more capable of doing gaming". Bill also pointed out that the "user could control the dots [droplets] like playing Pacman, something [. . .] to make incentives or rewards around eating food". These statements speak to our design intention for a "freeform" dish that uses games to retain children's attention to promote a balanced diet. Furthermore, Bill stressed that the Dancing Delicacies system could enable the children to engage with food and to "build an appreciation and understanding of the food they are eating [. . .] as opposed to treat[ing] it as a chore", so that the children and their parents can have a good time enjoying their meals together: "that [the playfulness] strengthens the relationship with food itself" as well as promote a "family-friendly engagement" (Bill). This theme speaks to our reflection on the "freeform" dish which can support future "playful HFI" design [7, 61].

Table 1: Participants' details for the follow-up interviews

Participant (pseudonym)	Occupation	Years of industry experience	Experience with food-related digital technology
Luke (48, M)	Manager of food innovation incubator	22	Experienced in promoting, coaching, and supporting digital technology for food businesses
Bill (30, M)	Product developer, design engineer (robotic food startup)	15	Expert in designing and developing food robotics and automation
Nance (25, F)	Technician/trainer in coffee industry	5	Uses digital technology frequently in food practice
Gabe (28, M)	Event organizer	5	No experience but knowledgeable about digital technology in the food industry
Kath (31, F)	Head pastry chef, former fine dining chef	10	No experience but has passing knowledge about digital technology in gastronomy

6.1.3 Theme 3: Synergy from real-time concept visualization. Participants indicated that Dancing Delicacies was a "tool" that could possibly offer a "tangible communication" (Bill) to facilitate the synergy between food creators and consumers. Bill stated that there are "barriers around communicating concepts from the user to the professional language", and the "accessibility and the consistency" of the language are different, because "it doesn't translate across the same consistent language use" between diners and food creators. In this regard, "it has [provided] a way to visibly show some processes to a diner" and can "actually illustrate specific colors, types, and flavors of droplets" (Bill). Creators then could "dispense tiny amounts and combine them in different ways" to show different outcomes (Bill). This aligns with our intention of an "instructional" dish. Additionally, the droplets could "mimic pixels that act like a display" that occurs in front of diners, and they could "rearrange them [pixels] to make a different image [. . .] that gives the information straight back to the creator" (Bill). This capability for real-time visualization could assist diners to precisely express the "nuance around flavor" (Bill) and helps creators recommend a certain flavor combination for the diners. This theme further confirmed that the "directional" dish could facilitate a synergy between the dish, its creator, and the diner.

6.1.4 Theme 4: Bounded taste exploration. Participants appreciated the "exploratory" quality of the system, particularly in a service context where diners are given the chance to explore and try new taste combinations. However, Bill pointed out that it might be risky to try new things, so the exploration would need to be "still within the bounds" of "what people are willing to, or where that decision is gonna end up". The system could provide a purposeful and "artificial constraint to get people to try new things", like a bounded taste exploration that can be "very discreet, like tiny sampling [. . .], or a winery cellar door-type experience, and sequential tasting" (Bill). This theme appears to confirm our design of the "directional" dish.

6.1.5 Theme 5: Timely cooking process. Participants appreciated that Dancing Delicacies enabled new ways to assist food preparation, consumption, and production through computation. For example, participants stated that "it would change the traditional way of making a dish for sure" (Kath), and that Dancing Delicacies could support a "highly innovative restaurant patron and chef" (Luke) to "push the boundaries of food and what they can do to create new dishes" (Kath). Kath shared how she envisions new ways of preparing and cooking: "The first thing that comes to mind is that the fats are almost always separated from most foods, like oil and vinegar. So, with this system, if you have a salad that is naked in the middle, and then you've got the dressing just going around it and mixing [to] avoid the acid being eaten into the lettuce". Kath suggested this timely cooking process could help creators build the perfect vinaigrette and master variations using different ingredients to balance the flavors and emulsify the mixture.

6.1.6 Theme 6: Flavor experimentation. Nance imagined a new tasting experience through precisely dispensing droplets in a specific blending ratio: "I really enjoy different possibilities and trying different flavors and combinations", Nance said, "for example, I can have a certain blending ratio [. . .], like 50% sourness and 50% sweetness in a same dish or drink, you just [need to] exclude or include some elements or flavors at some point in time on the same dish". Nance also pointed out that the different sweet-sour ratio reminded her of different types of acids in different fruits, so diners could adjust how they like to have the sour-sweet taste (more acid, like lime, or less acid, like mandarin). Similarly, Bill suggested that the system could automate the process of sample handling in a food production pipeline, because "the motility of droplets can be used for collecting and testing samples of beverages" (Bill), such as the "sugar content and pH level of a beverage product for quality and shelf stable lifespan control" (Bill).

6.1.7 Theme 7: "Fun education" for food and technology schooling. The participants also suggested that Dancing Delicacies could support "fun education" [13] as an engaging teaching aid for food and technology schooling. Luke pointed out that the system could be "assembled as a tool for young people to enjoy, play, and develop" and that its benefits go beyond "the food industry". He felt that "having this tool be used in a tech school would be really interesting" because there are lots of "purpose-built learning centers" for "teaching crossover STEM skills, such as food technology and programming" to young adults. Bill provided another perspective regarding food education: "I could see a lot of, like, educational use cases, like talking about combining ingredients in front of people or showing, for example, either sequential operations or preparation to show the effect of, like, dilution and strength of a food droplet solution on taste, things like that".

7 DISCUSSION: ORCHESTRATION OF CREATOR-FOOD-DINER INTERACTIONS

Our themes suggested that the dynamic trajectories could potentially evoke emotions, promote playfulness, facilitate real-time communication, and enable exploratory eating. We see these themes as design elements for an "orchestration" within the dining trajectories, where the dish, its creator, and the diner work together to create cohesive and engaging dining experiences. Such orchestration suggests a more nuanced interaction between food creator, food and diner compared with a traditional dining experience.

Orchestration can be deployed to shape what people do and feel in the context of a particular interaction [50]. In this regard, prior work argued that HCI has a lot in common with theatrical conventions in terms of orchestration, including "the variables of frequency, range, and significance", as well as "sensory immersion and the tight coupling of kinesthetics input and visual response" [50]. This aligns with how the presentation and movements of Dancing Delicacies dishes and the procedures of food preparing and eating were choreographed. The orchestration involves a series of activities (including activities of "behind the scenes" and "front of house") oriented toward the smooth running of the experiences [68], with creators programming (behind the scenes) and diners reconfiguring (front of house) a dish.

These interactions open an opportunity for food creators to dynamically engage in a discourse with the diner. For example, chefs, through their programming, could encode their concepts or a story into a dish or a food journey, thereby offering a space of aesthetic opportunities for diners to explore new tastes and experiences. Such an exploratory experience could be choreographed according to diners' personal preferences or dietary requirements. Furthermore, the Dancing Delicacies system facilitates a tangible way of communication beyond language with diners communicating to the chef their requirements for a meal through their interactions with the dish.

These qualities of computational food carry the potential to elevate the act of eating to the status of an artwork that is composed by the chef and then performed by the diner. However, the changes in the locus of control [41] also challenge the diner-creator relationship. For example, when giving the diner more agency in the creation, the creator might see their practice of expressing themselves as becoming limited. Our study suggested that the creators might want to set bounds for the diner's agency to ensure consistency in terms of the quality of their creations (dishes). Such challenges could lead to power tensions between diners and creators. However, they might also lead to novel value through co-creation. We believe that our work might help identify new ways in which creators and diners can interact and break through the traditional restaurant separation of kitchen and dining table.

8 LIMITATIONS & FUTURE WORK

Our work utilized EWOD technology. While this technology allows to efficiently manipulate droplets, it also limits the food materials to aqueous forms. The qualities of food droplets (i.e., surface tension and viscosity) determine whether the intended operations can be properly performed. Future explorations around other technologies might offer more possibilities and hence be useful for an additional understanding of the dynamic trajectories when designing computational food.

Also, although we have not fully explored the hardware's capabilities in this paper, we envision a variety of future interactive approaches to computational food via EWOD, in tandem with other media and input modalities. For example, EWOD technology could be used for food testing (safety analysis), as hinted in prior work [12]. Also, the electrodes could possibly be capable of joule heating [63], which could be leveraged for precise micro-cooking on the plate. We also envisage remote interactions, as suggested by the "telematic diner" [11]. For example, a user's action could be detected by one system and then this information could be transmitted to another system that reflects the change on the remote plate. We speculate that this form of distributed computational food may foster a sense of commensality over a distance [73] and we encourage future work in this area.

Furthermore, we have only demonstrated initial exemplar designs. We believe that many more opportunities exist for the future development of dynamic trajectories when designing computational food via more sophisticated computational capabilities. We also believe that further studies, along with collaborations, such as co-design workshops with culinary practitioners, diners, and technologists, could help with the exploration of these opportunities.

9 CONCLUSION

In this paper, we presented a design-led HFI inquiry resulting in a new system design called "Dancing Delicacies". We provided a design framework with four exemplar dishes to illustrate a new space of computational food. Through a preliminary engagement with expert practitioners from the hospitality industry, we derived seven themes to provide a first account of understanding dynamic dining trajectories when designing computational food. With this paper, we wish to inspire researchers and designers to envision a new future of human-food interaction.

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