“Human Chef” to “Computer Chef”: Culinary Interactions Framework for Understanding HCI in the Food Industry

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Abstract. Food is important and pertinent to everyone in more ways than one with its physical, social, mental, and cultural implications. The significance and interest in food and food-related activities are growing, and along with this movement there is a surge of human-computer interaction technologies in the food industry, also known as human-food interaction (HFI). There is a need to make sense of this burgeoning field, especially in a structured means to comprehend and analyze these technologies. The primary purpose of this paper is to introduce *Culinary Interactions Framework*, which provides a way of positioning and evaluating each HFI product and service in the food subsystem that focuses on the culinary processes, helps understand the HFI technology landscape, and identifies more nuanced points of interactions between human and robot. We also present ideas for future works to develop this framework further, with respect to more sophisticated levels of autonomy, expansion to other food subsystems beyond the culinary processes, and exploration of latent needs around HFI. The framework and further discussions are intended to better articulate, evaluate, and inform design and developments in HFI.

Keywords: Human-food interaction · Human-computer interaction · Human-robot interaction · Autonomy · Food · Food technologies · Cooking · Culinary process · Framework · Levels of robot autonomy · New product development · Ideation · Chef

1 Historical Background and Recent Trends in Human-Food Interaction Development

Computers entered the ecosystem of food production and consumption in the 19th century when vending machines were invented in England. Soon after, the concept of automation came not only to food production, but also to food service. The very first Automat was introduced in Philadelphia in 1902, and the New York-debut in 1912 enabled the Automat to spread out nationwide [1]. Inspired by the modernity and uniformity of automobile factories, as characterized by conveyor belts, buttons, and distributed labors, the Automat became the embodiment of technology at the manufacturing front in a commercial form. This automated service model birthed the rise of

M. Kurosu (Ed.): HCI 2017, Part I, LNCS 10271, pp. 214–233, 2017.
DOI: 10.1007/978-3-319-58071-5_17

fast food restaurants, with A&W Restaurants opening in 1919 and White Castle, McDonald, and Burger King joining its movement [1].

From the early 1950s, automation moved into private American households with inventions such as refrigerators and dishwashers. These sparked the emergence of the home appliance market as early forms of "personal service robots" [2]. Conceptualizations extending the home appliances to the smart age came with the prominence of spaceships in 1960s that brought the imagination of "smart home" to the public [3].

Since the Automaton and smart home appliances, robot development and commercialization in the food domain has been and is currently occurring at an unprecedented pace. All "three kinds of robots" classified by the United Nations (UN) have been on a steady rise, and this is true also for food technologies [2]. Examples of "industrial robotics" and "professional service robotics" in the food domain are as follows:

- Momentum Machines (http://momentummachines.com/) built a machine that autonomously produces 400 customized burgers in an hour without human input,
- Eatsa (https://www.eatsa.com/) takes orders via tablet computers and vends out freshly-prepared quinoa bowls, and
- Starbucks app (https://www.starbucks.com/coffeehouse/mobile-apps) allows you to order the drink you want at the location of choice on personal mobile devices.

From the three, the "highest expected growth rate," as forecasted by UN and currently holds true, is in "personal service robotics" [2]. This trend is also applicable for development of food robotics, and some examples of such are as follows:

- Moley (http://www.moley.com/) takes recipes and cooking methods of celebrity chefs and prepares world-class meals in personal homes with a robotic kitchen setup,
- June Intelligent Oven (https://juneoven.com/) allows users to broil, bake, and cook smart using its computer-based settings,
- Nomiku (https://www.nomiku.com/) automates and enhances part of cooking processes based on a sous-vide approach, and
- Starship Technologies (https://www.starship.xyz/) dispatches food delivery robots door-to-door.

As exemplified from emerging food technologies, computers and robots interpose between creator and end user in multiple ways. The most prevalent dynamics of interaction today seems to be HCHI (human-computer-human interactions). For example, when at Eatsa or when using the Starbucks app, there arises two human-computer interfaces, of one being an interface between the chefs (or baristas) and the orders and another interface between the customers and the devices.

Another popular trend is the conversion of what was originally an HHI (human-human interaction) model into an HCI model. Oftentimes, there is no direct interaction between the customers and chefs. Hence, we are prone to treating the chef as a robot, tastefully producing the food that is served. This dynamic has been heightened with the increasing automation in the production of fast foods, for which robots become the chefs. Such is the case of the automatic burger machine created by Momentum Machines. Taking the analogy further, the chefs are now "computers," the retailers are "interfaces," and the consumers are "humans." This is also the case with

Moley, a fully automated and integrated robot that cooks meals upon selection of the recipe and arrangement of the ingredients. In both instances, machines are not only transferring culinary experiences, but also replacing humans.

2 Problem Statement

Along with the rising trend in food technologies, academics and practitioners have started looking at food with the perspective of HCI since the early 2000s. Most research has been for development of specific applications such as cooking support, 3D fabrication, and nutritional consumption, to name a few [4–6]. Following the growing interest and development in food and HCI, HFI overviews and frameworks have also emerged.

However, in our investigation into food technology products and services, we found a dearth of academic research that covers and makes sense of the current trends in HFI development, despite steady growth in the general HRI research. For example, there have been extensive conceptual papers published in recent years to frame levels of robot autonomy [7] and to review frameworks of computational HRI to offer design guidelines for developing robots by considering social interactions with humans [8]. Yet, we have not found relevant literature that convey the human interactions with robot and computer chefs along with a series of culinary processes. We attribute this to the sudden growth in HFI technologies, for which the development of academic overviews and frameworks in the food domain have not been able to catch up. As there is no framework of HRI that is established for the domain of food itself, we have found a need for revisiting previous frameworks regarding HCI and HRI with a focus on food.

In HRI literature, the subject matter of the robot's levels of autonomy has been explored in depth. However, following the lack of research on HFI, the changes in the role of human with respect to the different degrees of autonomy of robots also have not yet been discussed for HRI of food technologies. With the rapid emergence of automated food products and services, we clearly see the need for developing frameworks that embrace the factors we listed above in order to suggest design guidelines and principles and to evaluate the effectiveness of available products.

In addition to the lack of HFI frameworks, there seems to be no connection made between the food-related activities, from food production to food waste, and the HFI products and services that address one or some of these activities. The food domain is expansive and the number of and kinds of stakeholders (e.g., farmers, chefs, distributors, consumers, etc.) involved in each of the subsystems and activities related to food vary at lengths. A relevant and comprehensive overview that aims to cover the trend of HFI research and interest recognizes that the food system is so large that "what is loosely referred to as 'food practices'—for example, shopping, eating, cooking, growing, and disposal—have grown out of the periphery of HCI research to become a central topic of interest in and of themselves" [6]. Although there are various attempts to define food practices [9, 10], it is difficult to find an overarching framework that embraces the myriad of food-related activities with socio-economic, technological, and environmental perspectives. Such an understanding will enable us to obtain a better sense of the HFI landscape, which includes what HFI products and services look like, how HFI developments occur, and how humans interact with these technologies.

The previous academic works in HFI can be summarized into two main topics, concerning (1) technological and computational challenges, and (2) socio-economic and cultural issues. The metaphor of "Star Trek-esque food scenario" seems to enlarge the opportunities of designing future food by addressing the technological part, yet we should not forget the core values of food as means of supplying nutrition, well-being, pleasure, connectivity, etc. [6]. Echoing this consideration, we also paid attention to research addressing human-centered approaches. For example, Grimes and Harper emphasize the significance of socially positive values of food technologies as "celebratory technologies" [4]. "Celebratory technologies," inspired by the "positive aspects of people's interactions with food," contrast with "corrective technologies" that aim to curb undesired user behavior and problems associated with food [4]. This is an important contribution that encourages addressing aspects other than "problems" around food, but the dyadic framework may be an oversimplification. We have therefore found a need to build a consolidated framework that addresses other sources of inspiration for the development of HFI technologies. This framework will inform and support the creation of guidelines for designers and developers.

3 Culinary Interactions Framework

3.1 Food Systems

We begin with a review of food systems as it is necessary to understand what activities happen in the world of food and what sort of food interactions between stakeholders occur during the activities. There are many different ways to define and display food systems based on varying perspectives of food traditions, food policy, food security, sustainability, regional boundaries, etc. [9, 10]. Among them, we look at food systems from production ("farm") to consumption ("table"), summarizing the primary activities in Table 1 below. Among the broad range of food-related activities, we have decided to focus on the culinary and serving pursuits in order to discern a series of human activities and to investigate the interactions between "human" and "computer/robot" chefs. We have decided to include "serving" in our scope of work, as it is a critical step that connects a chef/cook to a customer, by exchanging feedback in between.

3.2 Culinary Processes and Serving

"Culinary" process defines practices related to kitchen or cookery. Although cooking is one of the oldest human practices, codifying this practice as knowledge and processes has been relatively recent. Auguste Escoffier greatly contributed to the industrialization and modernization of the restaurant kitchen. His book, *Le Guide Culinaire* [11], introduces the culinary processes from ingredient preparation, sanitation, and cooking methods to presentation and services [12]. Horng and Hu [13] claim there are two sides of culinary processes, a survival-based side and a cultural-aesthetic one.

Table 1. Primary food-related activities in the food subsystems. (Table 1 includes both the industrial (B2B) and consumer (B2C) food subsystems and activities.)

Subsystems	Examples of activities
Production	Farming, growing, harvesting
Storage	Packaging, labeling, freezing
Culinary processing	Preparing, cooking
Foodservice	Serving, catering, transporting, wholesale/retailing
Food data management	Communicating, collecting, storing and accessing data (e.g., nutrition, culinary know-how, and knowledge, etc.)
Consumption	Eating, digesting
Waste	Composting, recycling

Whereas the former side of cooking is generally operational, we view the latter part as creative. The aim of this paper is to generate a conceptual framework that displays how a human and/or computer chef creates a new dish/meal and how they cooperate/collaborate for a creation of food. Thus, it was necessary to review the food-related activities mapping with the new product development (NPD) process, often framed in six steps: planning - concept development - system level design - detail design - testing and refinement - production and ramp-up [14].

Drawing parallels between the NPD and food creation/development, we framed the processes for the use of HCI in food into the following six steps: ideation - procurement - preparation - cooking - plating/assembly - serving. The first five steps occur in the back-side of house, which usually take the form of a kitchen, and the serving part takes place in the front-side of house, which could be in the context of a restaurant, takeout/delivery service, or even in the domestic context. We articulate these steps in order to systematically study and analyze the processes in food creation/development. We recognize that these steps may not occur in the order presented and are interchangeable in some cases, but we have chosen to follow this order as they are standard protocol that we follow, and because by establishing this can we then expand upon it further.

Ideation is the stage during which chefs generate a concept of dish/meal by considering multiple factors such as dining ambiances, financial limitations, customer needs, prep/cooking times, etc. A big part of ideation is inspiration, which plays a significant role in bringing creativity and motivation to chefs before and/or during the ideation stage. Inspirations come from seasonality, nutrition and health concerns of customers, socio-economic contexts of consumption, food technologies, globalization/internationalization of cuisines, special ingredients, etc. Studies about renowned chefs reveal that these inspirations are used as the basis for creative methods of cooking [15]. Once the ideation of a concept of dish/meal is completed, the ingredients, tools, and materials need to be in-hand and available for use. We call this process **procurement**, and this can be achieved by various means such as grocery shopping, retail/distribution, etc. Another means is "foraging," which is carried out by a professional procurement personnel to search and source the raw materials. Oftentimes packaged goods are kept in reserve before their use, thus we include in this step the concept of storage, which considers packaging size, shelf life, and quantity. **Preparation** stage is after all the procurement is completed. Tasks are distributed to the relevant cooks/chefs, usually based on their experiences and expertise. The activities associated with preparation ranges the whole gamut, from washing, rinsing, and plucking, to chopping, slicing, and mashing. Once the preparation of raw ingredients is completed, **cooking** begins. Cooking is a series of activities whereby raw ingredients are transformed generally by a reaction to heat, although there are exceptions such as Japanese sushi and Peruvian ceviche. Cooking methods vary based on food cultures, regions, technologies, traditions, economics, tools, etc. For the last two decades, technology and science have played a significant role in the cooking world by birthing new cooking techniques and tools/appliances. Molecular gastronomy, experimental cuisine, and multi-sensory cooking are such examples. **Plating/Assembly** is the final step at the kitchen before the finished dish/meal is served to the customer. Plating includes choosing an appropriate container to serve; balancing colors, textures, and portions; and finishing the food at the right temperature. As this step usually completes the final products, it requires an aesthetically-pleasing presentation. According to an experiment at Oxford University [16], people perceive better taste and dining experience by an enhanced visual presentation of food. This study argues for the importance of an aesthetic appeal, by claiming that "people eat by eyes first." **Serving** food is the step in between cooking and eating, and this can be manifested in various types from professional individual service (waiter/waitress), take-out service, self-service, group service (i.e., buffet), etc.

So far, we have described the food-making processes based on "human" chefs' activities as the basis for HFI development. These six steps will serve as a conceptual foundation to view the HFI activities from the next section.

3.3 Primitives of Robotics in HFI

The rise in development and popularity of food technology is currently disproportionate with our understanding of HRI and robot autonomy categorized in the food domain. There is also a lack of a comprehensive understanding on how the HRI viewpoint fits into the bigger food system.

As developments in HFI are based on the concepts foundational to HRI, we build upon the established three primitives of robotics: sense, plan, and act (SPA) [17]. Here, we do not distinguish between the three paradigms of the primitives (i.e., hierarchical, reactive, and hybrid deliberative/reactive). Although the dynamics and causalities between the primitives are important, our aim is to bring more clarity to the overall understanding of HFI. Thus, we have constructed a framework that explains SPA primitives for HFI in its relevant context and captured examples of HFI products and services that help illustrate what the change from human to robot entails for these primitives.

As we have previously discussed, we constructed the *Culinary Interactions Framework* for the front-house and back-house culinary processes. In our examination of the primitive of "sense," we have found that breaking it down to who, what, when, where, and how helps paint a more comprehensive picture of the wide range of sensory

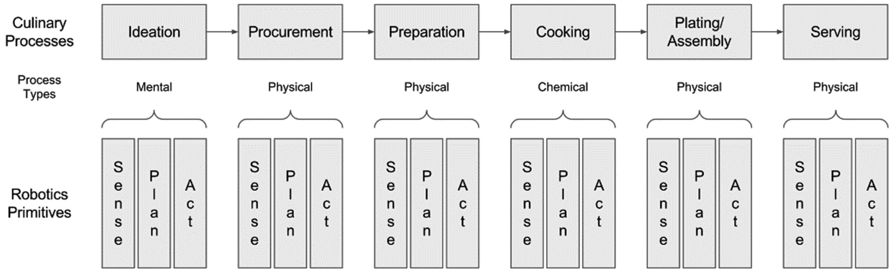

Fig. 1. Robotics primitives within the culinary processes and serving

input that gets translated into the output of sensed information. As for the primitive of "plan," the directives that are derived as output from the sensed information are done so by algorithms. There are many variations in the algorithms—it could be implemented by a human or robot, it could be based on subjective judgment or objective empirical data, it could be static or evolving as it learns, etc. However, one constant goal for the "plan" primitive is to take all the input to derive a directive that leads to "a well-balanced and optimized final decision and action," whether it is in the form of a sequence, method of choice, etc. Lastly, the primitive of "act" is the "actuator commands that stem forth usually from the "how" asked in the primitive of "sense" [17].

Having laid out the primitives of sense, plan, and act—primitives that are developed for robotics but comes from conventional human roles and actions—the tasks that the robot can perform in place of the human becomes very clear. With this clarity of tasks performed by the robot, we are able to articulate the role of the robot, identify the points of human-robot interaction, and further redefine autonomy in the current context of HFI.

3.4 Levels of Autonomy

We have applied the rigor and framework of HRI research to our analysis of HFI, including the concepts of autonomy appropriate for this domain. As stated by Beer et al., "in HRI, there are two schools of thought in conceptualizing autonomy: (1) higher robot autonomy requires less frequent interaction; and (2) higher robot autonomy requires higher levels or more sophisticated forms of interaction" [7].

These two conceptualizations, though important, are not embedded in the definition of autonomy proposed by Beer et al.: "the extent to which a robot can sense its environment, plan based on that environment, and act upon that environment with the intent of reaching some task-specific goal (either given to or created by the robot) without external control" [7]. With HFI in particular, we also find that the word "environment" may limit our understanding with its implication for physical boundaries. Therefore, we propose the following as our definition of autonomy for the clarity of this paper:

The quantitative and/or qualitative extent to which a robot can **sense** its environment, constituents in the environment, and/or relevant sensory signals for a designated goal; **plan** based upon such sensory input to obtains directives; and **act** upon one or a combination of these inputs (sensed information or directives) with the intent of reaching a **defined task-specific goal** without external **stimuli**.

Here, by "quantitative" we mean the number of tasks the robot is capable of performing continuously on its own without human interaction, and by "qualitative" we mean the level of difficulty, sophistication, or complexity of tasks. With the SPA defined for each of the stages within the culinary process, the *Culinary Interactions Framework* helps to better understand autonomy of HFI.

Figure 1 and Table 2 exemplify tasks in the culinary process and these tasks can be completed either by a robot or human. By identifying the tasks that can be carried out by an HFI product or service through the *Culinary Interactions Framework* (Fig. 1 and Table 2), we are able to get a clear picture of the tasks that can be or are carried out by the robot instead of the human, leading to a comprehensive overview of the robot's role. Furthermore, by making connections between the tasks described, we can deduce the number of tasks or processes the robot is able to perform without human interaction. In other words, HFI products and services that have longer chains of tasks can be interpreted as having "higher robot autonomy." With the numeration of continuous task-completions made possible by this framework, we are able to start quantifying "robot autonomy" with regards to required frequency of human interaction.

3.5 Human Roles and Points of Interactions

The second conceptualization of robot autonomy deals with the quality of the interaction. "Sophisticated forms of interaction" can be difficult to define, as they may be subjective. Though difficult, we can begin to address the sophistication level of interaction by further distinguishing the tasks that the robot implements (i.e., answering the "why" question in the completion of task) of either human-supporting or self-implementing, or both.

For example, in the case of the robot implementing an action, often the human's role becomes one that is supervisory. This is a passive role that may or may not lead to sophisticated action-taking. In the event that there is no intervention, the human is on standby, a rudimentary level of interaction. On the other hand, if a technical failure occurs, higher levels of interaction will be necessary: while the robotic system senses, identifies, analyzes, and notifies the human of the issue, the human learns about and tries to fix the issue. Such scenarios will also be applicable for our interactions with HFI as the basic interactions between humans and robots are similar. In addition, we are certain that the level of sophistication will increase, especially in the domain of food, as we often associate food and the practices around it with our emotions and feelings. With a focus on these two core intangible manifestations and increasing development of social robots, higher levels of HFI will be possible and Table 2 will be helpful in identifying the various ways in which "higher levels of interaction" or "sophisticated forms of interaction" can be explored.

We aim to address each of the primitives of robotics and levels of autonomy by exemplifying some of current products/services in Tables 3–6, which supports the identification of the points of HFI through the articulation of:

Table 2. Examples of robotics primitives within the culinary processes and serving.

Culinary Processes	Ideation			Procurement			Preparation		
SPA	Sense	Plan	Act	Sense	Plan	Act	Sense	Plan	Act
Examples of SPA Tasks	**Who:** Who will be eating the food–babies or people with dietary restrictions? **What:** What is in season? What are the nutritional needs of the consumers? What is the context of this meal? What kind of recipes are available? What is the budget for the meal? What kind of emotions or experiences will the meal trigger? **When:** When will the food be served–when it is done, at a specified time, etc.? **Where:** Where will the food be served–at home, at a facility, at a restaurant, etc.? **How:** How will the food be procured, prepared, cooked, and served? How will the food look, feel, smell, and taste? How will the consumers feel about the dish/meal and the ambience?	Decide which of these sensed conditions to consider for a well-balanced and optimized final decision and action for ideation–sequence, method of choice, etc.	Create or decide upon a menu, food concept, etc. and on the compatible or appropriate cooking methods/general guidelines for preparation work.	**Who:** Who is ordering, searching, or delivering? **What:** What ingredients are available and what are missing? What transportation methods are available for delivery to the kitchen? **When:** When will the ingredients be procured–right before the preparation stage, weeks in advance, while cooking, etc.? **Where:** Where will the ingredients be sourced–locally or globally? **How:** How will the ingredients be acquired–delivery by car, plane, etc.? Will it be packed as is in a styrofoam box with dry ice, as frozen, or by a refrigeration unit inside vehicle maintained at its optimal temperature?	Decide which of these sensed conditions to consider for a well-balanced and optimized final decision and action for procurement–sequence, method of choice, etc.	Shop, purchase, and acquire new ingredients or reuse what's in the fridge, inventory, etc.	**Who:** Who will be preparing–washing, chopping, julienning, slicing, etc.? For whom is the preparation necessary–the cook, the consumer, etc.? **What:** What are the ingredients to be prepared? What tools will be used to prepare the ingredients? **When:** When should each of the ingredients start being prepared? **Where:** Where should the ingredients be prepared–at which station, on which chopping board, in which bowl, etc.? **How:** How will the ingredients be prepared–will they be diced or sliced, will they be kept in a particular container or method after the preparation work before the actual cooking, etc.?	Decide which of these sensed conditions to consider for a well-balanced and optimized final decision and action for preparation–sequence, method of choice, etc.	Wash, cut, dice, julienne, smash, roll, scrub, mix, freeze, shred, etc.

(*continued*)

Table 2. *(continued)*

Culinary Processes	Cooking			Plating/Assembly			Serving		
SPA	Sense	Plan	Act	Sense	Plan	Act	Sense	Plan	Act
Examples of SPA Tasks	**Who:** Who will be cooking–head chef, sous chef, robot, etc.? For whom is the food cooked? **What:** What is going to be cooked? What tools or facilities will be utilized for cooking? **When:** When will the cooking happen–right before or days before serving? **Where:** Where will the cooking occur–in a stove, on the grill, out in the backyard, etc.? **How:** How will the food be cooked (methods)?	Decide which of these sensed conditions to consider for a well-balanced and optimized final decision and action for cooking–sequence, method of choice, etc.	Sautée, pan-fry, bake, fry, broil, etc.	**Who:** Who will assemble and plate the food? Who decides the final display and readiness of the food for serving? **What:** What is the food to be assembled together? What are the tools used to assemble the dish? Which plate or platform will be used to display the food? What rules of plating will be applied? What will be the plating proportions? **When:** When should the assembly and plating occur–after heating up the plate, right after the food has been cooked? Does the dish need to rest before serving? **Where:** Where should the assembly occur–next to the stove, at another station, in front of the consumer, etc.? **How:** How will the food be assembled or plated together–three-dimensionally, by painting, in clockwise direction, or from hot to cold?	Decide which of these sensed conditions to consider for a well-balanced and optimized final decision and action for plating/assembling–sequence, method of choice, etc.	Plate, assemble, mix, pile, drip, etc.	**Who:** Who will be serving–by a server or a robot? Who will be served–for an individual, the group, all the customers, or for takeaway customers or those dining in, etc.? **What:** What will be served–dish, condiments, etc.? **When:** When will the food be served? **Where:** Where will the food be served–at the counter, where the customer is seated, at a buffet setup, for delivery, etc.? **How:** How will the food be served–all at once or at separate intervals, at room temperature or at extreme temperatures, from left to right or vice versa, etc.? How long will the servicing take?	Decide which of these sensed conditions to consider for a well-balanced and optimized final decision and action for serving–sequence, method of choice, etc.	Service à la russe (serve individually over multiple times in a formal dining context), service à la française (serve a group meal), handover (takeaway/to-go meals), deliver, etc.

- Switch in performer of tasks, from human to robot,
- Delineation of robot roles and the respective changes in roles of human,
- Points of interaction between human and robot, and
- Types and forms of interaction between human and robot.

With our framework, listing, visualizing, and understanding the points of interaction between human and robot become easier. This, in turn, allows designers in HFI development to systematically create a variety of interactions between human and robot.

3.6 Interpreting "Celebratory Technologies"

In our framework, we have identified tasks that the robot takes on in lieu of the human. Addressing these task-oriented outcomes with the skew of HRI may easily lead to "corrective technologies" [4]. This is especially true for tasks in the culinary processes, as these technologies aim to prevent, support, or substitute human behaviors/activities. Though an important distinction, the naming and descriptions of corrective and celebratory technologies may convey that the former only solve "problems," eliminating negative emotions without producing positive feelings [4]. Although the motivation for HFI development may be focused on such, the results are not as the model may suggest.

Corrective technologies are not mutually exclusive from celebratory technologies, and they may also engender the positive emotions and benefits that the celebratory technologies aim to fulfill. We find that what is classified as examples of "positive interactions" achieved by celebratory technologies are usually the by-products or higher goals of the products and services developed. HFI that tackle conventional problems of efficiency, productivity, safety, and delegation, may also produce benefits that were not articulated during the design process and/or prior to use.

Looking at our framework, the emphasis of celebratory aspects is especially important at the ideation stage. Through a systematic exploration in the ideation stage of the primitive "sense" with questions such as "what kind of feelings are we trying to imbue with the food" or "what kind of emotions or experiences will the meal trigger," we can develop ways in which we can stimulate positive values including creativity, pleasure, connectedness, and curiosity.

4 Application of Culinary Interactions Framework

We apply relevant examples of HFI products and services to the framework (Fig. 1, Table 2) to result in Tables 3, 4, 5, and 6. By utilizing and garnering insights from the framework, we can identify who does what (i.e., human or robot performing which task and what the change in task implementer entails). This, in turn, equips the designers and developers with a systematic way of distinguishing each of interaction points between the robot and human, and therefore allow them to comprehensively address how these interactions will occur.

We have looked into commercial examples such as Moley, Amazon, and Eatsa in particular to show the variety of specific SPA tasks that covers the range of all the culinary processes (Tables 4, 5, and 6). In doing this, we have also made a simple distinction between human-supporting and self-implementing to address "why" a certain task is carried out by the robot. This is an important distinction that demonstrates the robot's purpose of task and scope of work. It also exemplifies how the framework can be further broken down to capture nuances of information that are crucial for HFI analyses.

4.1 Moley

The Moley has by far the most number of continuous tasks performed without human interaction or intervention (all tasks within the cooking and plating/assembly steps are self-implementing). This reflects its respective higher level of autonomy than any other HFI product or service we are reviewing. As for the qualitative extent of robot autonomy, we have yet to conduct primary user-testing research to make a definitive statement. However, we infer that the level of interaction between human and robot will be more sophisticated than current HFI products and services [18]. Such an inference stems from Moley being able to fulfill both human-supporting and self-implementing roles for the ideation and preparation stages, a combination that allows for multiple types of interactions, which can be indicative of higher forms of interactions. Our inference is also based on the functions that are to be included, such as sensing and analyzing human movements to not only replicate the human chef's culinary processes for the recreation of a meal, but also for future collaborations between the human and robot.

4.2 Amazon

Amazon provides a range of levels of autonomy through various procurement services that it provides. The Amazon Dash Button, for instance, was introduced to deliver a seamless ordering experience by providing a physical button for certain products that customers frequently need to refill depending on when the item was last ordered, how often the customer purchases, etc. In each of the SPA tasks, it is evident that Amazon plays both the human-supporting and self-implementing roles by utilizing its various platform products and services. Furthermore, the extent of self-implementation of the procurement action is prone to change with Amazon's "flying warehouse" or airborne fulfillment center (AFC) and drones that are to be used in conjunction in the future [19].

4.3 Eatsa

Eatsa, offers a waiter-less experience at the front-side of house. When the Eatsa kiosk or app takes an order, it transmits the order to "human" chefs/cooks in the kitchen, and informs the staff which dishes to be placed at which windows once cooking is completed. Although menu offerings are selective, customers are able to customize their meals based on specific needs without verbalizing their order to a server. Moreover, they no longer need to wait in line. As a modern interpretation of the Automat, Eatsa has digitized the ordering and serving systems, and effectively brought forth the illusion of digitized cooking (but actually run by people behind the screens).

Table 3. Application of *Culinary Interactions Framework* with HFI technologies. (▲ = Human-supporting. △ = Self-implementing)

Culinary Processes	Ideation			Procurement			Preparation			Cooking			Plating/Assembly			Serving		
SPA	Sense	Plan	Act	Sense	Plan	Act	Sense	Plan	Act	Sense	Plan	Act	Sense	Plan	Act	Sense	Plan	Act
Moley	▲△		▲				▲ △	▲ △	▲ △	△	△	△	△	△	△			
June										△	△	△						
Foodini	▲△	▲ △	▲							△	△	△	△	△	△			
Momentum Machines							▲ △	▲△	▲△	△	△	△	△	△	△			
Amazon				▲ △	▲ △	▲ △												
Eatsa																▲	△	▲△

Table 4. Application of *Culinary Interactions Framework* with examples of Moley.

Culinary Process	SPA	Description
Ideation	Sense	**Human-supporting**: In the case that the user wants a chicken dish, Moley finds recipes that it can cook with chicken as the main ingredient **Self-implementing**: Moley collects, stores, and brings up recipes in its extensive library of recipes of various celebrity chefs.
	Act	**Human-supporting**: Although the Moley doesn't decide what the consumer ultimately eats, it helps the consumer decide what to eat or order from Moley with all the information included in its library of recipes by food types, celebrity chefs, etc.
Preparation	Sense	**Self-implementing**: Moley senses ingredients that are laid out. **Human-supporting**: Moley notifies the user whether all the necessary ingredients for the dish have been prepared.
	Plan	**Self-implementing**: Moley plans its course of action: which ingredient to start chopping first, which ingredients have multiple steps in the preparation process, where it should place the prepared ingredients into, etc. **Human-supporting**: With the preparation steps laid out by Moley, users are able to time or strategize their part of the preparation accordingly.
	Act	**Self-implementing**: Moley dices, juliennes, slices, etc. to perfection all the ingredients that have been laid out in front. **Human-supporting**: User customization is possible with the preset settings of the ingredients that are ready to be cooked.
Cooking	Sense	**Self-implementing**: Moley senses the pre-cooked, prepared ingredients that are ready to be cooked.
	Plan	**Self-implementing**: An action plan is created with consideration of what to cook first, degree of "cookedness" necessary for each sub-stage of the cooking process, optimal strategy for sequencing, etc.
	Act	**Self-implementing**: Moley cooks according to the plan that it has drawn up, frying or flipping the food with perfect timing.
Plating/Assembly	Sense	**Self-implementing**: Moley senses when the meal is cooked to completion, what the resulting volume of food is (portion), what the finished food temperature is, etc. In addition to the edible product, Moley also gathers information on various plating rules and assembly methods.
	Plan	**Self-implementing**: With the various factors for plating and assembling taken into consideration, Moley plans the sequence of activities.
	Act	**Self-implementing**: Moley plates/assembles the final dish together so that the meal ends up the way that the chef has intended.

Table 5. Application of *Culinary Interactions Framework* with examples of Amazon.

Culinary Process	SPA	Description
Procurement	Sense	**Human-supporting**: Amazon keeps order information. **Self-implementing**: Amazon automatically recognizes when items need to be refilled and alerts its inventory management system when the Dash Button is pressed or subscription settings are activated to restock olive oil, canned tuna, etc.
	Plan	**Human-supporting**: Taking all the input together, Amazon creates plans and algorithms that create the most accurate predictions and recommendations for the user's food purchases. **Self-implementing**: From the various inputs, including the Dash Button and subscription service, Amazon creates an action plan that includes when to get the food items from inventory, pack into boxes, ship for delivery, etc. to perform based on the automatic settings of fulfillment.
	Act	**Human-supporting**: Amazon receives customer's orders, payment, etc. **Self-implementing**: Amazon optimizes the delivery routes and time, and dispatches the delivery personnel.

Table 6. Application of *Culinary Interactions Framework* with examples of Eatsa.

Culinary Process	SPA	Description
Serving	Sense	**Human-supporting**: When chefs/cooks in the kitchen finish cooking and are ready to place the plate behind the vending window, Easta senses who the meal is for, which vending windows are available, etc.
	Plan	**Self-implementing**: Eatsa decides which vending window the final meal is to be placed in to provide a playful, streamlined, and customized experience.
	Act	**Human-supporting**: Easta notifies staff where to place the finished meal. **Self-implementing**: Once the plate is placed in the vending window, Eatsa displays the name of customers on the windows.

5 Conclusions and Future Directions

5.1 Conclusions

With *Culinary Interactions Framework*, we have attempted to address the challenges we have identified in HFI development, as discussed earlier.

First, we bring the sophisticated understanding of HRI to the food domain, including task distinctions and levels of autonomy. We have explored how these make sense within the HFI context. We have also demonstrated a systematic way of identifying all the task-specific goals (both operational and the non-operational, such as the "cultural-aesthetic" side) that the robots can address. We can now quantify "robot autonomy" by counting the number of continuous task-completions possible without human interactions. We also bring up the possibility of a qualitative aspect in which we can begin to understand how to rate the sophistication level of human-robot interactions. We will discuss this further in future works.

Second, we have attempted to bridge the gap between academic research and the sudden growth of HFI technologies in the real world through this investigative paper. We have met our intent to create a conceptual framework that current HFI technologies can be applied to and we consider this the first step in bringing together the theoretical and practical worlds.

Third, our framework allows us to examine every point of HFI, which not only increases our awareness of interaction points, but also can lead to the creation of design guidelines and principles for interaction types, forms, etc. Such guidelines and principles will allow for more user-centered HFI development and concurrently help devise a scheme for evaluation of the effectiveness of available products.

In addition, the framework also provides a structured method of viewing the subsystems of food. Articulating and creating similar frameworks for other subsystems of food will enable streamlining between the subsystems. The consequent clarity and seamlessness will allow designing for an integrated food system with a holistic understanding.

Last but not least, we have built upon the academic research related to HFI and have drawn meaningful conclusions from them. In future works, we will expand on this further by addressing the seeming inefficacy of the distinction between corrective and celebratory technologies through the discussion of latent needs, an important concept in user-centered design.

5.2 Overview of Future Directions

Through the development of our framework, we foresee how academic work in HFI can expand. Future works that we propose can be grouped into the following:

- Refinement of framework with articulation of robotic autonomy,
- Expansion of the framework to other subsystems within the larger food system (e.g., production, foodservice, waste, etc.),
- Further development of the framework with a focus on users' latent needs,
- Research of social impact and repercussions resulting from HFI development.

Greater Articulation of Robotic Autonomy. The framework we have developed thus far provide the fundamentals for a better understanding of the types of HFI that exist today, trend in HFI development, and the larger HFI landscape. We find that expansion upon and adaptation to *Culinary Interactions Framework* will be invaluable as one can further incorporate details and nuances that are not yet captured. For example, the framework shows nodes of tasks that the robot performs, but we have not created the connections between these nodes, such as determining the necessity or directionality of the connections. A clear visualization with this sort of data, along with quantified levels of autonomy, embedded is needed.

We have also started discussion regarding the qualitative extent of robotic autonomy, but this ought to be further explored through more in-depth user studies and analyses of the HFI technologies. One direction we suggest in addressing interactions that require "higher levels or more sophisticated forms" is the application of the hierarchical structure of the kitchen to the inspection of the sophistication levels of autonomy. It is conventional knowledge that the higher up on the hierarchy, the higher your level of decision-making and involvement are. Having a higher placement in the hierarchy may imply not only implementing and being responsible for higher levels of tasks themselves, but it may also entail higher levels or more sophisticated forms of interactions with others, such as morale management, knowledge transfer, team dynamics, collaboration, group learning, etc. Hence, one of the future directions is to translate such existing models into the concept of autonomy in HFI.

Expansion to Other Food Subsystems. With our mapping, we have also kept our scope of the breakdown to the front-house and back-house processes of food (culinary processes and serving), and we are currently validating the framework for current and future HFI technologies. However, there are many subsystems of food as identified in Table 1, each of which have their unique processes that involve different stakeholders in a variety of ways. We hope to continue charting the robot's multitudinous roles in the bigger process beyond the six steps we have identified: ideation - procurement - preparation - cooking - plating/assembly - serving.

As the progress towards *Internet of Food (IoF)* continues, articulating, distinguishing, and mapping the processes of each of the subsystems will allow for a holistic understanding of the all the activities and stakeholders pertaining to food as well as the dynamics of influence. More importantly, it will also allow for seamless development in HFI connections and relationships as the food data from each subsystem would be gathered, analyzed, and utilized through a common data architecture. Furthermore, this seamless connection between the various subsystems will also bring greater efficiency and sustainability in the whole food system.

Exploration of Latent Needs. The current framework that we have developed is task-based, as per the widely-accepted HRI academic literature. Taking such HRI research as the foundation for our framework, we defined autonomy as being SPA implemented with the "intent of reaching a defined task-specific goal without external control." The goals being "task-specific" naturally makes it difficult to include in its scope the deeper, intrinsic needs of the users that are neither easily nor often expressed as "tasks." However, chefs/cooks do not simply perform operational and replicated tasks, but also enhance and innovate new dish, drawing from inspirations such as creativity, emotion, and/or senses. As exemplified in Table 2, questions addressing such are in the "sense" primitive, especially in the ideation stage of the culinary process.

Although we find that the manifestation of HFI technologies are not as mutually exclusive as implied by the corrective and celebratory distinction, we agree that HFI development can also stem from positives [4]. The "six positive aspects of human-food interaction" that Grimes and Harper suggest as starting points for "future possibilities for HCI" are creativity, pleasure and nostalgia, gifting, family connectedness, trend-seeking, and relaxation. These positives are often articulated as higher goals in NPD or are effects that often appear as a by-product from addressing the more explicit needs. Moreover, these are all factors considered by some of the best chefs from celebrity restaurants to our homes, usually in the ideation step of the culinary process.

Taking the design and ethnography approach, we can see that these positives are rather "latent needs and desires": people often have the innate desire and/or need for creativity, pleasure and nostalgia, gifting, family connectedness, trend-seeking, and relaxation [4, 18]. The importance of discovering and addressing "latent needs and desires" is highlighted in design literature, such as *Designing Interactions* [20], which states "when you are trying to understand the latent needs and desires of potential users before a design is created, it is important to learn about their existing habits and context of use—things they are rarely able to tell you about explicitly".

Referring to the examples listed by Grimes and Harper and classifying them as "latent needs," we have started constructing Table 7 below. In Table 7, we expand upon the latent needs whilst creating a distinction between the level or unit of influence these have. These latent needs were discovered from our exploratory pilot study on U.S. college students with a sample of 11 participants. Our preliminary findings demonstrate that there is a potential causality between explicit needs and latent needs. Although the respondents listed "efficiency," "affordability," and "better health outcomes" as benefits from HFI (addressing explicit needs), they also mentioned the individual "pleasure" and "socially connected" influences food technology has had in their lives (addressing latent needs). They also found it, "interesting" and "fun to see and imagine".

We have also classified the latent needs as having influence on the "individual" or "social" level as per the qualitative results garnered. We believe this is a very important categorization especially for designers as this unit of influence will greatly impact the technological development in its form, shape, functionality, etc.

Expanding upon the above latent needs of users is crucial to gain a better understanding of what future users may expect and desire for HFI technologies. As social robotics and other HRI development proceeds, so will that of HFI technologies. Just as HFI has benefited from the expansion of HRI technologies, the reverse of HFI development based upon a better understanding of the latent needs can also be helpful to the larger HRI development. We believe that this is an urgent task and therefore will continue to conduct qualitative research to finalize our conclusions and to develop framework regarding these latent needs.

Uncovering and treating these latent needs as inspirations for HFI development, in addition to conventional explicit needs such as efficiency, productivity, safety, etc., may lead to innovative designs in technologies and interactions. We hope to expand upon other latent needs that exist, observe what kinds of designs stem forth from this new directionality, and evaluate the similarities and differences in technological manifestations that address the same latent needs such as collaboration, sustainability, etc. Such a framework to help identify latent needs users have for food technologies will help designers understand their users at a deeper level and allow for more effective practices and implementations in design.

Table 7. Exploration of latent needs pertaining to food experiences.

Level of influence	Latent needs	Description
Individual	Creativity	The desire for originality, authenticity, novelty, etc. (could be for self-expression, self-fulfillment, etc.)
	Pleasure	Stimulating the senses in a way that brings hedonic experiences
	Nostalgia	Stimulating past memories and contexts associated with experiences
	Curiosity	Interest into trends, types of cuisines, knowledge of cooking, etc.
	Relaxation	The state of feeling free, whether it is obtained through the mental association we have with particular food or through the chemical and physical responses (e.g., anti-stress after a glass of wine)
Social	Collaboration	Enjoyment from working towards a shared goal with others (e.g., cooking, dining, cleaning, etc.)
	Empathy-building	Cultural sharing/understanding
	Sustainability	Consideration of environmental values
	Connectedness	Feeling and affirmation as a social being through family relationships, friendships, etc.
	Gifting	Contentment arising from selfless acts or consideration for others

Social Concerns Regarding Future Food Experiences. Though the speculation of future food seems quite welcoming to a lot of us, we urge to pay attention to potential social concerns, such as an accountability issue. For instance, who is going to be responsible for the food poisoning caused by human-robot cooked meals? Such accountability concerns have been heftily raised in the autonomous vehicle development, and the same analogy would soon apply for the food sector.

Lastly, we would like to bring up the potential issue on the absence of human factors. When cooking altogether becomes "food manufacturing" or "food engineering," where can we find humanized/humane interfaces and elements in this process? Replacing low-wage human labors by robots is yet another large issue with the current projection of ubiquitous food manufacturing. The top 10 low-wage occupations in U.S. include cashiers, food-preparation workers (in fast food contexts), and cooks, and the current movement towards automation makes us concerned about the future of employment [21].

These are but a few of the social concerns that have emerged through our preliminary research, and these matters ought to be captured and considered in HFI development.

References

1. Diehl, L., Hardart, M.: The Automat: The History, Recipes, and Allure of Horn & Hardart's Masterpiece. Clarkson Potter, New York (2002)
2. Thrun, S.: Toward a framework for human-robot interaction. Hum. Comput. Interact. **19**(1–2), 9–24 (2004)
3. Lynch, T.W.: The History of Smart Appliances (2013). http://ovens.reviewed.com/features/the-history-of-smart-appliances
4. Grimes, A., Harper, R.: Celebratory technology: new directions for food research in HCI. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 467–476. ACM (2008)
5. Svensson, M., Höök, K., Laaksolahti, J., Waern, A.: Social navigation of food recipes. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 341–348. ACM (2001)
6. Comber, R., Choi, J.H., Hoonhout, J., O'hara, K.: Designing for human–food interaction: an introduction to the special issue on 'food and interaction design'. Int. J. Hum. Comput. Stud. **72**(2), 181–184 (2014)
7. Beer, J., Fisk, A.D., Rogers, W.A.: Toward a framework for levels of robot autonomy in human-robot interaction. J. Hum. Rob. Interact. **3**(2), 74–99 (2014)
8. Thomaz, A., Hoffman, G., Cakmak, M.: Computational human-robot interaction. Found. Trends Robot. **4**(2–3), 105–223 (2016)
9. Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M.: Human domination of earth's ecosystems. Science **277**(5325), 494–499 (1997)
10. Ericksen, P.J.: Conceptualizing food systems for global environmental change research. Glob. Environ. Change **18**(1), 234–245 (2008)
11. Escoffier, A.: Le Guide Culinaire: The First Complete Translation Into English. Mayflower Books (1921)
12. Kim, S.H.: Open Innovation Ecosystem: Chez Panisse Case Study. UC Berkeley Doctoral Dissertation (2013)
13. Horng, J.S., Hu, M.L.: The impact of creative culinary curriculum on creative culinary process and performance. J. Hospitality Leisure Sports Tourism Educ. (Pre-2012) **8**(2), 34 (2009)
14. Eppinger, S., Ulrich, K.: Product design and development. McGraw-Hill Higher Education, New York (2015)
15. Kudrowitz, B., Oxborough, A., Choi, J.H., Stover, E.: The Chef as Designer: Classifying the Techniques that Chefs Use in Creating Innovative Dishes (2014)
16. Michel, C., Velasco, C., Gatti, E., Spence, C.: A taste of Kandinsky: assessing the influence of the artistic visual presentation of food on the dining experience. Flavour **3**(1), 7 (2014)
17. Murphy, R.: Introduction to AI robotics. MIT Press, Cambridge (2000)
18. Burgess, M.: Robot chef that can cook 2,000 meals set to go on sale in 2017 (2017). http://factor-tech.com/robotics/17437-robot-chef-that-can-cook-any-of-2000-meals-at-tap-of-a-button-to-go-on-sale-in-2017/
19. Spieler, G.: Your warehouse in the sky (2017). http://www.huffingtonpost.com/geri-spieler/your-warehouse-in-the-sky_b_14119132.html
20. Moggridge, B., Atkinson, B.: Designing Interactions. MIT Press, Cambridge (2007)
21. Frey, C.B., Osborne, M.A.: The future of employment: how susceptible are jobs to computerisation? Technol. Forecast. Soc. Chang. **114**, 254–280 (2017)