CounterIntelligence: Augmented Reality Kitchen

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ABSTRACT
The kitchen is a complex and dangerous multi-user work environment that can benefit from augmented reality techniques to help people cook more safely, easily and efficiently. We present Counter Intelligence, a conventional kitchen augmented with the projection of information onto its objects and surfaces to orient users, coordinate between multiple tasks and increase confidence in the system. Five discrete systems gather information from the kitchen and display information in an intuitive manner with special consideration for directing the user's attention. This paper presents the design of these systems and results of initial evaluations.

Author Keywords
Augmented Reality, Context-Aware Computing, Interaction, Smart Rooms, Projection Techniques, Product design, Image Understanding.

ACM Classification Keywords
Categories and subject descriptors: H.4.m [Information Systems Applications]: Miscellaneous, Kitchen; J.7 [Computers in Other Systems]: Consumer products, Kitchen counter, refrigerator, cabinets, sink, range.

INTRODUCTION
Domestic kitchens are technologically complex laboratories where multiple users carry out different, complex tasks with numerous tools, work surfaces and appliances. As with any laboratory used simultaneously by multiple people, accidents can happen if two different activities collide. The tools of the kitchen are numerous and complex, often requiring instruction before they can be used. The appliances, despite their automation, rarely provide feedback on their status or prompt users for interaction.

CHI 2005, April 2-7, 2005, Portland, Oregon, USA.
ACM 1-59593-002-7/05/0004.

Kitchens are natural candidates for augmented reality interfaces because there is a high need for users to remain in contact with physical reality while using a number of sophisticated tools that benefit from digital information [3]. By sensing the location of tools and ingredients, the temperature of surfaces and food, and the needs of the user; Counter Intelligence can provide information to coordinate and instruct cooks on the use of the kitchen. Although the physical aspect of the kitchen remains unchanged when the system is off, useful information can be overlaid on nearly every surface of the space: the refrigerator door, range, countertop, cabinets, and faucet (see Figure 1). In each case, the quality and quantity of information projection needs to be tailored to the amount and type of attention directed at each task.

Figure 1. Augmented Reality Kitchen: information projection on the refrigerator (1), the range (2), the cabinet (3), the faucet(4) and drawers(5).

RELATED WORK
DigitalDesk and the *DigitalDesk Calculator* demonstrate the power of digital information augmentation to improve the functionality of a traditional writing desk [2]. By augmenting drawing and writing with the advantages of digital manipulation, this tangible interface demonstrates the benefit of augmented reality in a task-specific environment. In the DigitalDesk calculator, the work surface serves as a touch screen by recording finger taps on a projected calculator interface with a camera and microphone.

CounterActive teaches basic recipes by projection and interaction on a kitchen counter [2]. A capacitive sensing array under the countertop turns it into a touch-screen for interacting with the instructional, step-by-step projection. In both *DigitalDesk* and *CouterActive*, the projected information is limited to a single user at a single surface and can not project information where users actually direct their attention while performing many cooking tasks.

The *Everywhere Display* is capable of projecting information on nearly all of the surfaces and objects of a space, as well as creating camera-based interfaces wherever the projection lands [4]. One kitchen of the future uniformly tiles the backsplash with LCD displays, microphones, cameras and foot switches [6]. But indiscriminately plastering the environment with video-quality projection does not answer the most pressing needs of an augmented reality kitchen, which are to provide the necessary information without interfering with cooks or cooking. Attention is a limited resource that must be carefully directed if users are to feel more confident while performing complex tasks in a new environment.

Various projection techniques are suited to different scenarios in a graphically annotated kitchen [1]. For example, water temperature can be usefully inferred from the simple projection of colored light – red for hot and blue for cold. Similarly, work surfaces benefit from different types of information projection when they are used for eating (entertainment) or cooking (instruction). Projection onto real-world objects can be an effective means of adding significance to digital graphical user interfaces [5]. We have proposed a series of interfaces that project information of appropriate complexity onto the refrigerator, cabinets, countertop, as well as the water and food actually being prepared. In this paper, we discuss the design considerations that led to each interface and its current appearance, as well as the scenario and user evaluations carried out in this context-aware kitchen.

IMPLEMENTATION

We have designed and built a series of discrete context-aware systems to monitor and inform the most commonly performed tasks in a residential kitchen. These five systems collect information from the environment and project task-specific interfaces onto the refrigerator, cabinets, countertop, and food: FridgeCam, RangeFinder, Augmented Cabinetry, HeatSink, and Virtual Recipe. Together, these systems reduce the complexity of interacting with the kitchen and eliminate many sub-steps that can confuse or endanger users.

To design the augmented reality interface, we began with a careful consideration of the user's attention and the best ways to present information in general. The space was designed according to several demonstrated principles of attention theory: exogenous cues, endogenous cues, and serial and parallel visual searching.

Existing kitchen interfaces like the faucet handle or the dials on the range require users to focus their attention away from the task of using the water or cooking food in order to read or adjust the interfaces. In many cases (such as two-handed work) the interfaces require a user to interrupt their task. Since attention is a limited resource, moving the user's focus away from the center of attention even slightly can hinder task performance.

Augmented reality projection can show information and project interfaces directly on the task being performed. This type of exogenous attention cueing requires the least mental processing. In the case of the faucet, we project the temperature as a simple color on the water itself, eliminating the need to look at the faucet handle. For more complex tasks, we employ endogenous cues to direct attention as efficiently as possible. For example, when a recipe calls for the user to retrieve something across the room, we project the recipe in front of the user, an endogenous cue (like an arrow) mid-way between the user and their task, and finally an illuminated drawer handle where the user needs to place their hand to retrieve the object. Endogenous cues require more processing than exogenous cues, but have been shown to reduce reaction time by helping guide attention with respect to no cueing. By painting the space with attention cues wherever they are needed, we can simplify tasks and increase user confidence.

Figure 2. An example of endogenous cueing (left) and exogenous cueing (right) in the augmented reality kitchen.

By the same token, we employ the principle of pop-out in visual search to speed up the process of locating individual items throughout the kitchen. Cooks must often perform a serial search within cabinets and of one cabinet after another when looking for a specific tool or ingredient. Serial search is inefficient since its duration is directly proportional to the number of items being searched. In comparison, parallel search describes the condition when the time required remains unchanged for a certain quantity of items searched, until a certain threshold is reached. To simplify the process of finding items in the kitchen, we allow the user to perform a parallel search where the desired object pops out through colored illumination of cabinets themselves. Even practiced users of the space should experience a reduced reaction time and more confidence when the objects to concentrate on are illuminated.

Figure 3. Virtual Recipe

Figure 4. RangeFinder

Virtual Recipe

For user evaluation of the Augmented Reality Kitchen, we guide users through a step-by-step recipe inspired by the instructional methods employed in *CounterActive.* Instead of being projected on the countertop alone, two multimedia projectors display Virtual Recipe on the cabinets in front of users as well as on the work surfaces of the range and counter. We decided to separate the areas where users interact with the Virtual Recipe from the area where cooking work is accomplished, so that physical gestures used for one task do not conflict with those for another. Since the cabinet doors are vertical, their function can only be as display and interface whereas the countertop only receives passive information display. Users navigate the steps of the recipe by passing their hand in front of projected "virtual buttons" interpreted through a vision recognition algorithm. Users with wet or dirty hands don't have to touch any surface as webcams detect the change in appearance of the buttons when the hand passes in front of them. The vision-based interface works through a PC running a C++ program with the Microsoft Vision SDK library. The "virtual buttons" can be placed anywhere in the kitchen, so that users can access the recipe wherever they need it. When a certain step calls for an item stored in the cabinets, the Virtual Recipe cues the Augmented Cabinetry to illuminate the appropriate drawer handle where the desired item is located. As part of a model of the user, task and the environment of the kitchen, Virtual Recipe also interfaces with RangeFinder to cue certain types of information, such as food temperature when frying oil or cooking duration when boiling pasta.

Initially, the time lag to recognize hands passing in front of the virtual buttons was excessive at over 2 seconds. By carefully illuminating the area in front of the cabinets while covering the background with matte gray surface, we were able to increase the sensitivity of the system so that virtual buttons are triggered on average 0.7s after a user places their hand in front of the projected button.

RangeFinder

While we can easily control the temperature of our range burners, it is impossible to accurately gauge the temperature of food in a pan or the duration of cooking without additional tools and distraction. RangeFinder is a remote infrared thermometer that measures the surface temperature of food in pans on the range and projects useful information regarding the food temperature and cooking time directly onto the cookware and the food itself. RangeFinder can currently determine when food reaches a desired temperature (for example, when water boils) and time the duration of the state. In this way, RangeFinder precludes the need for the additional steps of setting a separate timer or using a hand-held thermometer. In future versions RangeFinder will prompt projected images of the food as it should appear when fully cooked, providing an intuitive instruction to novice cooks.

In our implementation, RangeFinder is a modified commercial infrared thermometer mounted inside the range hood. The sensor communicates to a PC running Virtual Recipe through a PIC-based microprocessor. The response is almost instantaneous, but the low resolution of the sensor means that we use average temperatures of each burner area to determine the true temperature of the food. The system is accurate to ± 2 ºC, and can aid in determining duration of simmer or boil or to keep an oil from burning.

FridgeCam

Users of a kitchen often open the refrigerator too often and for too long because they are unsure of its contents or layout. FridgeCam is an augmented reality interface that projects the spatial information about the contents of the refrigerator directly onto the door for the purpose of reducing the time that the door stays open as well as the number of times the it is opened. By capturing different views each time the refrigerator door is opened and projecting an image on the outside of the door, FridgeCam helps users locate refrigerator contents in three dimensions. In future applications, FridgeCam can be used to remotely look within the refrigerator from a cell phone or PDA to help remote users shop for meals.

FridgeCam works through a wide-angle CCD camera mounted to the inside of the refrigerator door so as to be at maximum throw when the door is fully open. The camera is triggered by a vision-recognition system running on a PC in C++ using the Microsoft Vision SDK library. A blue LED inside the fridge is recognized by the PC and triggers the camera to capture a view of the refrigerator's contents. The current FridgeCam is limited to the vertical resolution of a multimedia projector that is shared with Virtual Recipe. Pilot studies reveal that a low-resolution display hampers recognition of the refrigerator's contents because users often feel more confident when they can read text on labels too small to be projected. The advent of high-resolution displays and projectors in combination with multi-dimensional projection like FridgeCam will allow highly insulating enclosures such as the refrigerator door to perform better at helping users find items than transparent doors.

Figure 5. FridgeCam: projection on the refrigerator door (left), location of digital cameras (right).

Augmented Cabinetry

One of the most time-consuming tasks in a kitchen is finding items in cabinets, especially for first-time users. While transparent cabinet doors can help identify the objects near the door, they add to the visual complexity of the space and can actually increase search time by incrasing the number of items in the visual search. Augmented Cabinetry is an active inventory system that reduces the time required to locate items in the kitchen cabinets without adding visual complexity to the space. LEDs embedded in translucent cabinet handles illuminate on cue from the virtual recipe system. If the required items are located far from the user, we cue the final location with an arrow projected midway between the user and the item in question. In future versions, search engines and the inventory system will be combined to provide immediate cues to direct the user's attention as fast as possible to the items they desire. We will augment the inventory system with a combination of capacitive sensing and RFID in order to keep live inventory of utensils, containers and dry storage goods even when they are kept in uncommon cabinets.

We expect Augmented Cabinetry to have the greatest impact on reducing search times for first-time users of a kitchen, but the combination of endogenous cueing (arrows) and exogenous cueing (illuminated handles) should reduce search time for all users by increasing user confidence. For this reason – and to make the control study equivalent – we instructed users in the evaluation to familiarize themselves with the contents of the kitchen drawers before beginning the evaluation.

Augmented Cabinetry works by a hard-wired network of illuminating drawer handles controlled by a PIC-based microcontroller through the Virtual Recipe system on a PC. We are developing future versions in which power harvesting and radio communication reduces the need for a hard-wired network to drive the spatial cues.

Figure 6. Augmented Cabinetry.

HeatSink

In a multi-user kitchen, faucet water temperature varies according to the temperature of the water in the line and of the last use. Typically, users can only determine the actual temperature of the water by touching the stream, but this requires at least two actions: touching the water and drying the hand(s), in addition to any necessary adjustments to the faucet control. To reduce these steps, HeatSink projects colored light inside the stream of tap water according to the temperature of the water. LEDs in the faucet head color the water stream blue when the water is cold, and red when the water is hot. The intensity of the illumination varies with the distance from the threshold temperature. Dangerously hot water causes the red light to flash. The colored illumination projects the information directly where users need to see it, and allows them to make any necessary adjustments without wetting their hands.

The system works through a solid-state sensor and a PIC-based microcontroller driving pulse-width-modulated LEDs mounted around the faucet aerator. The aeration of the water increases its ability to diffuse the colored light. The reflective quality of a stainless steel sink enhances the ability of the colored water to illuminate the point where the water scatters, often where it is being used.

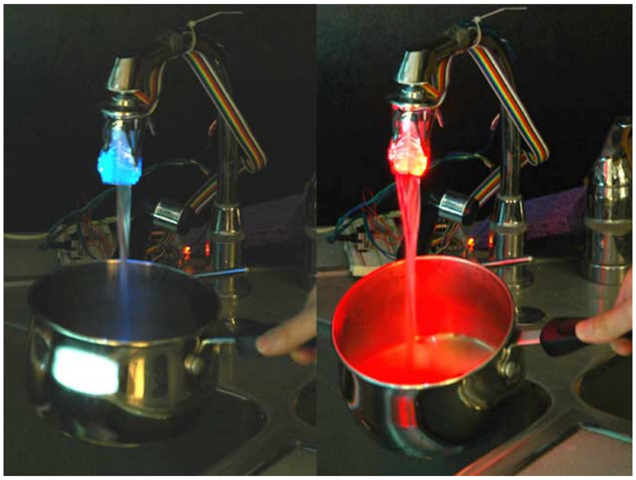

Figure 7. HeatSink.

System Architecture

The augmented reality kitchen has multiple input systems: a camera-based virtual button interface above the cabinets, cameras to observe fridge content, and a remote infrared thermometer over the cooktop. Output systems consist of two video projectors placing digital annotations on the fridge, range, cabinets and countertop and illuminated drawer handles. HeatSink is a device which operates independently to reflect water temperature. The software interface is written in Macromedia Director 8.5 with SerialXtra and TrackThemColor Xtra.

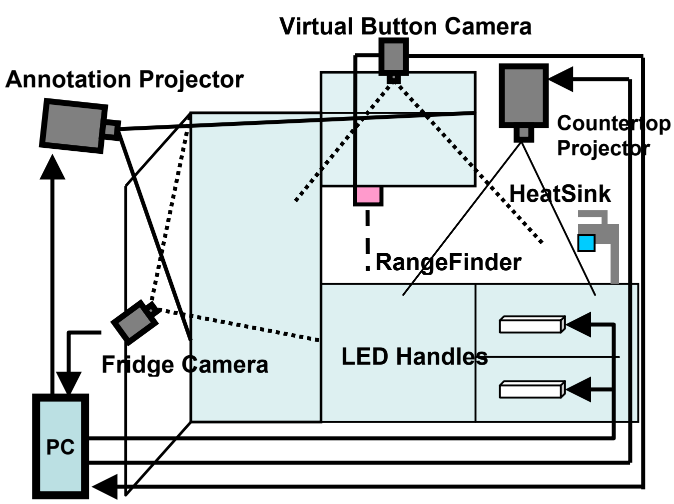

Figure 8. System diagram

PILOT STUDIES

Pilot studies of Counter Intelligence were carried out as part of the design process to determine that the system was as successful as a traditional system and to determine which aspects of the task improved or suffered from augmented reality. We succeeded in making the novel system perform as well as traditional systems in directing users despite the system's novel appearance.

We designed an evaluation protocol to take advantage of each system. In the user test, people are asked to carry out a simple recipe – soft-boiling an egg. In carrying out the four-step recipe to soft-boil an egg, users interface with the refrigerator, cabinets, countertop, sink and range. A paper recipe outlining all of the steps is provided to the control group. Before the evaluation, each participant spends three minutes familiarizing themselves with the contents of the refrigerator and relevant cabinets. This is designed to better gauge the effectiveness of Augmented Cabinetry and FridgeCam, since our control group used neither. We hope that users will find it easier to locate items in the cabinets even when they know where the items are located because the augmented cabinetry is simpler to use than our own memory. Our hypotheses are that the information projections simplify the process by reducing steps or the time required to perform them. We also expect that users will feel more comfortable and confident using the augmented kitchen.

In performing even the simplest recipe, there are countless steps involved. For example, the first step of soft-boiling an egg consists of many sub-steps: “put an egg in a pan and fill the pan with cold water” actually entails finding a pan, finding an egg, turning on the water, determining that the water is cold, filling the pan, and turning off the water. Each sub-step is actually subject to additional complication if, for example, the pan is hard to find. Counter Intelligence seeks to reduce these sub-steps by providing feedback on the status of things in the kitchen automatically. By visually communicating the temperature of the water, HeatSink eliminates the steps of touching the water and drying hands. By automatically measuring the temperature of the range, RangeFinder eliminates the steps of observing boil, setting a timer and turning it off. Augmented Cabinetry can vastly reduce search times, but even when a user knows the location of something the system of attention cues should make the process of concentrating on finding things faster and easier. This is based on the hypothesis that while we often know what we are supposed to do, many delays occur when we simply forget or lose concentration. Self-illuminated drawer handles can shift higher cognitive processes requiring memory to lower cognitive processes requiring pop-out in visual search. FridgeCam can reduce steps to the point of having a measured impact on the time the refrigerator door spends open.

Iterative Design

A Pilot study was conducted to examine the interface design of the virtual recipe and find out potential issues regarding the user’s attention. Five initial users were given a recipe on the counter to see if they could follow it. The study tested if a user could follow the digital projected instructions. As shown in Figure 9, the first recipe design is a flowchart with arrows to go forward and backward. The arrows failed to lead users to proceed. Traditional elements of GUI design did not work in the augmented reality projection. For example, the arrows that typically indicate navigation did not make themselves understood immediately to pilot study users. Successive design iterations replaced the arrows with hands and finally added textual instruction to make the interface self-evident. By the end of these pilot studies, the augmented reality kitchen performed as well as a paper recipe in guiding users to a successful conclusion.

Together with the virtual button interface, we played audio feedback to indicate that the button was successfully "depressed." Initially confusing multiple tones were replaced with a single bell when the button was triggered.

A flowchart-like recipe allowed users easily to recognize the sequential order of steps in a recipe. But in the study, users were expecting a highly interactive interface with projections. The little circles indicated as sequential steps were falsely recognized as buttons. The projection that shows the temperature measurement from the RangeFinder isn't helpful enough for users because they don't need to measure temperature to make decisions. Instead, the shapes, smells, and colors of food are more relevant to decide how it cooked. In order to provide helpful information to users, we changed it present the actual state of water, such as warming or boiling, within the Virtual Recipe system.

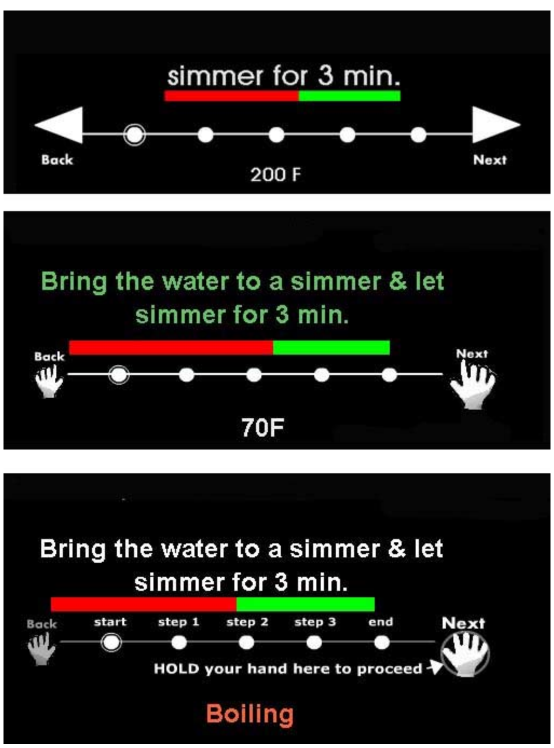

Figure 9. Evolution of Virtual Recipe GUI design

In the pilot study, some users also got stuck in the first few minutes looking for instructions to proceed and get familiar with the system. Text instructions were easier to keep users oriented, such as "HOLD your hand here to proceed." The third image represents the improved interface.

Evaluation Protocol

To evaluate Counter Intelligence, a study was conducted in the augmented reality kitchen. An experimental group of 5 and a control group of 8 were asked to perform the same recipe in the same space with the same physical interfaces. The experimental group used the augmented reality kitchen with interactive recipe system.

The aims were to evaluate the system based on three criteria: the performance of the technology, the performance of the system, and the users' aesthetic perception of the system. Users responded to written to pre-test and post-test questionnaires and were videotaped to evaluate progress . The first pilot study recipe contains four steps:

1. Put one egg into a small pot & fill the pot with enough HOT water to cover the egg.
2. Bring the water to a simmer & let simmer for 3 min.
3. Remove the pot from the stove & run COLD water over it until it is cool.
4. Serve the soft-boiled egg in an egg holder with a spoon

Results

While not significantly faster than the control group for several metrics, the major results of the experimental group is that even with a small sample size it is obvious that a scenario laden with new and unusual tools for doing things was at least as good as those that people are used to. The metrics employed were timing of video observation and pre- and post-test questionnaires.

Observation

The results of observation reveal that the augmented reality system had a slight advantage over a control group in the location of items, and a slight disadvantage in the preparation of food. There were slight improvements in the average measured times to find the first item in the recipe (9.6s v. 10.6s) and to find the second and third items in the recipe (22.8s v. 24.8s) between the experimental group and the control group, although these results were not statistically significant. There was a slightly slower performance to begin using the range (60.6s v. 52.4s) and to find the last tools (61.4s v. 43.9s) between the experimental group and the control group, although these results were not statistically significant. Users required an average time of 14.2s to begin using the novel camera-based interface.

Questionnaires

Pre- and Post-test questionnaires asked the users to rate the difficulty of finding items in refrigerators, using a range, using a faucet, finding items in cabinets, and following a recipe. The lack of statistical difference between control group and users in all but the cabinets indicates that the augmented reality interfaced behaves on the whole as well as a traditional recipe.

The illuminated drawers showed a statistically significant improvement over control drawers (paired samples t-test $p<.05$). Users usually opened more drawers than we expected, because they were looking around the room and ignored drawers that were beckoning them with lighted handles below their waist. Future improvements we can make would be to draw people's attention with blinking illumination or sound. In the control group, users wasted more time on searching in vain until they found what they needed.

CONCLUSION

This paper presents an augmented reality kitchen with five digital augmented systems that reveal the status of tools and surfaces in the space in order to enhance the kitchen experience. We proposed that the projection of digital information onto the objects and surfaces of the kitchen can increase user confidence; and can better orient a user in space. The combination of digital augmentation technologies was proven to be generally as robust and reliable as traditional recipe interfaces. Pilot studies and user evaluations reveal that ambient, attention-sensitive projections were most useful. This project reveals two major lessons: the advantage of exogenous cueing in locating items in a familiar environment and the advantage of paper recipes over sequential, digital ones in allowing for a multi-tasking approach.

The iterative design process reveals a number of directions for future research to make the augmented reality systems more familiar and effective. We already determined that the design of augmented reality projection for the kitchen is counter-intuitive to traditional GUI designers. While we learned to make our interfaces more and more intuitive, a great deal of work remains to replace lengthy text cues throughout the space with image- and sound-based natural instruction. Further studies will examine the sort of cues more broadly to include video and photo instructions along with text and graphics.

The sensing systems could be improved to include more information about the location and performance of users throughout the space. The same webcams already used in our system could be re-positioned to measure users' locations, as well as which drawers are being opened and which appliances are in use. Then our system could make more intelligent choices about the type of information that would be most useful to users and the best places to project camera-based interfaces.

This paper presents a system whereby a space can be inexpensively layered with additional useful information to improve safety, performance and user confidence in a kitchen. The novel system reveals the potential of real-world augmented reality to distribute interfaces and sense the condition of activity throughout a task-oriented environment. As projection and sensing techniques drop in price, it will be possible to combine cameras and projectors into a single appliance that can layer any environment with information that can be tuned to individual users and their tasks. The main advantages of these systems are that they do not require changes to the infrastructure of the space and can automatically add functionality without physical bulk. As we develop Counter Intelligence we expect that the lessons learned will have broad applications to industrial, commercial and residential spaces. As our world becomes more multi-functional these augmented reality systems will be able to shepherd us through new experiences to broaden our ability to interact with the built environment.

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