# Living with Tableau Machine: a longitudinal investigation of a curious domestic intelligence

**Zachary Pousman, Mario Romero**
College of Computing / GVU
Georgia Institute of Technology
Atlanta, GA 30332
{zach, mromero}@cc.gatech.edu

**Adam Smith, Michael Mateas**
School of Computer Science
University of California, Santa Cruz
Santa Cruz, CA 95064
{asmith, mmateas}@cs.ucsc.edu

## ABSTRACT
We present a longitudinal investigation of Tableau Machine, an intelligent entity that interprets and reflects the lives of occupants in the home. We created Tableau Machine (TM) to explore the parts of home life that are unrelated to accomplishing tasks. Task support for "smart homes" has inspired many researchers in the community. We consider design for experience, an orthogonal dimension to task-centric home life. TM produces abstract visualizations on a large LCD every few minutes, driven by a set of four overhead cameras that capture a sense of the social life of a domestic space. The openness and ambiguity of TM allow for a cycle of co-interpretation with householders. We report on three longitudinal deployments of TM for a period of six weeks. Participant families engaged with TM at the outset to understand how their behaviors were influencing the machine, and, while TM remained puzzling, householders interacted richly with TM and its images. We extract some key design implications for an experience-focused smart home.

### Author Keywords
Ambient intelligence, interactive art, evaluation techniques, casual information visualization, information visualization, sensors, activity characterization.

### ACM Classification Keywords
h.5.2 user interfaces, h.5.1 multimedia information systems.

## INTRODUCTION
Ubiquitous computing researchers have spent many years augmenting domestic spaces with technology in the quest to create "Smart Homes" [1]. Smart homes add proactive intelligence to domestic life, to support such tasks as cooking [20] and managing to-do lists [17]. But much of everyday life may not be amenable to a hierarchical decomposition with clearly delineated tasks, and as such, these parts of life may be overlooked as the home becomes smart. For example, from a strictly utilitarian perspective, a household relaxing and "hanging out together" may not complete some well proscribed task, but its rich emotional and social usefulness may still be felt by householders.


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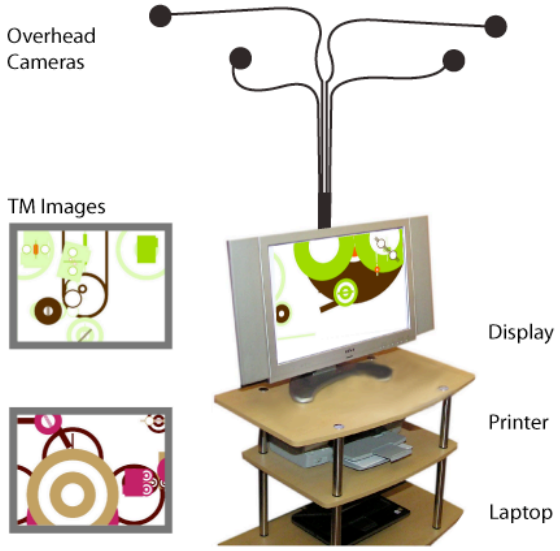


**Figure 1:** Tableau Machine parts. Four overhead cameras, LCD screen, keypad, printer and computer. TM images are on the left.

Tableau Machine (TM) attempts to provide support for reflecting on home life, both individually and as a household [15]. As an artifact, TM has a large LCD screen that shows a continuous series of images, each of which depicts an abstracted view of life in the home gathered from a set of ceiling-mounted cameras (See Figure 1).

We designed TM to make visible the experiential parts of home life, the way that the home feels when it is in a certain state or situation (whether or not that situation is part of accomplishing a task). This brings the normal background of "everyday life" to the foreground, and pushes task focused activities to the background [13]. Instead of focusing on tasks, we created a system that functions as a social entity in the home and as a mirror of home life. TM creates pictures of the home across social

states and configurations, such as "family game night" or "wistful dinner on the last day of spring break." Though TM senses where people (or pets) are and represents some social metrics about them, it does not apply canonical labels, such as "cooking" or "cleaning up" or "excited" or "mad" to the situations. Instead, TM makes each situation available for human inspection, interpretation, and meaning making.

We deployed TM into three Atlanta, Georgia (USA) area households, so that we could witness the ways in which a sensing and interpreting intelligent entity would be received by families. Would they be able to interpret its images, and would they find interpreting the images fun and worthwhile? Would TM create engaging and entertaining commentary on home life? Would TM be seen as an intelligent mirror of home life? Our deployment study catalogs a host of ways that family members interacted with TM, how their understanding and interactions changed over time, and how TM became a new and curious way for householders to think and talk about home life. This research contributes to an emerging domain for ubicomp technologies, those designed for the deeply experiential parts of human life, and not just for a particular task. Our study provides some new evaluation methods and design guidance for the ubicomp researcher who is working to transform the home.

TM also suggests some contributions to task-focused ubicomp systems. First, the deployment traces whether, how, and in what ways individuals and households formed mental models of technology artifacts. Second, householders may also ascribe personality to systems as Sung *et al*. found in householder engagement with Roombas, a robot vacuum cleaner [19]. Third, TM shows how households formed relationships to a system that watch or monitor them, a cycle of meaning making we call *co-interpretation*.

The outline of the paper is as follows. First, we explain our design goals for TM (Section 2) and the details of implementation (Section 3). In Section 4 we present our study methodology and analyze data from three longitudinal deployments. In Section 5 we discuss our results and in Section 6 we compare TM to related work. In Section 7 we present implications for the design of ubiquitous computing systems with an experiential (as opposed to a productivity) focus. Lastly, we discuss conclusions and future work.

## TABLEAU MACHINE: DESIGN GOALS

TM departs from many "smart home" systems since it provides support for reflection and contemplation, non-task activities in the home. TM senses activity not to recognize it to take action, but to provide a window into the unexamined background of life, and novel perspectives on household rhythms and tasks. As Rogers notes, "we should also be designing [systems] to be exciting, stimulating and even provocative—causing us to reflect upon and think about our interactions with them." [14]

### Sensing in the home

Ubicomp systems for domestic spaces must sense human activity in order to store, display, and transmit it. Sensing, especially when continuous and invasive, can cause householders to reject a system outright, or to treat it with suspicion.

TM is intended to serve the occupants of the home. It is not a surveillance system. Surveillance is literally "watching from above", and describes an asymmetrical relationship where the viewer gets information while the viewed parties receive none. Mann coined the term "sousveillance" to describe watching oneself for one's own ends [9]. TM performs sousveillance; it is a sensor and interpreter of home life for householders, not for anyone else. The characterizations it creates need not be useful to outsiders.

### Defamiliarizing domestic life

Defamiliarization is a technique that designers use to challenge assumptions about some topic or situation. Bell *et al.*, introduce defamiliarization to the HCI community, a design strategy to look at things from a novel perspective by removing them from everyday and familiar contexts and understandings [2].

McCarthy and Wright bring the phenomenological concept of felt life to bear on technology interactions [10]. TM attempts to provide a novel view into the felt experience of living, playing, working, and fighting in the home. TM employs non-discrete mapping between data and display. By avoiding simple one-to-one mappings between data and display, the household has more space to engage in co-interpretation, that is, for the system to serve as a provocation rather than a simple reporter of the state of the home. If done correctly, householders should have the sense of the system as an independent, non-human subject, who has its own interpretation of the activity engaged in by the user; living with such a system long-term becomes a process of getting to know TM's peculiar subjectivity, and of actively constructing meanings relating TM's interpretation to each householder's lived experience.

### Characterizing domestic activity, not recognizing it

Activity characterization is different from activity recognition, which is a concrete and discrete problem, with clear success metrics. Activity characterization succeeds or fails based not on objective truth, but a co-created agreement between the subjects (householders) and the observer (Tableau Machine).

We note that as system designers in these very personal and very ambiguous domains, we are not judging the household or the householders. We recognize that every home is different and are not trying to influence householders into some optimal configuration. We do not believe that the home is driven by a desire to optimize, nor would we have any idea what optimum looks like for any household. Our goal is to give them information from which to think more deeply about these topics.

### Aesthetic emphasis

With TM's design, we want to strike a balance between aesthetic concerns and technical feasibility. We want to be

expressive about the full range of characterizations or moods in the home. TM's images need to strike a balance between being stylistically consistent while making different home states distinguishable by occupants. We have been inspired and influenced by interactive and generative art works as well. We take special inspiration from Cohen's *Aaron*, a generative painting system [11], *American Varietal (US Population, by County, 1790-2000)* [16], a public artistic depiction of census Bureau data, and Office Plant #1, a kinetic sculpture that moves through transformations based on the emotional tone of an individual's email exchanges [4].

## TABLEAU MACHINE: IMPLEMENTATION

TM contains three modules: a sensor, an interpreter that characterizes household activity, and a generative expression system. In this section, we describe how these modules work together to create an interpretive mirror of life in the home.

Physically, TM consists of a laptop computer, an LCD screen, a color printer, and four overhead cameras. We place the computer and printer on a small media cart and perch the LCD on top, and we position TM so that it can be seen from many vantage points in the home (see figure 1).

### Sensing Activity

The sensing subsystem contains four Logitech QuickCam 5000 cameras. The cameras connect to the computer over USB-to-ethernet extenders so we have flexibility in how we place cameras to achieve maximal coverage in socially important areas of the home. Socially important areas of the home include living rooms, dining areas, kitchens, and transit areas like hallways and foyers. No cameras are placed in private spaces such as bedrooms or bathrooms.

Though cameras may seem an invasive intervention in a domestic setting (and we report on householder's feelings about this in the analysis section), they are a simple technology that provides high-resolution motion detection. Cameras, when compared with other motion detectors, provide very high spatial granularity as well as temporal sampling (we poll cameras approximately once per second). In order to protect privacy, we do not store the raw camera images. Instead each is analyzed and then immediately discarded.

TM computes motion using Adjacent Frame Difference (AFD), an established computer vision algorithm. AFD subtracts pixels of a given frame from the previous frame, finding changed pixels and thresholding the difference. Therefore TM senses only motion. However, humans are rarely perfectly still. Even watching a movie or reading on the couch, they shift, scratch, and fidget. Thus, after aggregating, camera-based sensing can capture all of a person's waking life.

Not all motion is equal. In the home, activity has different meanings in different places. Harrison and Dourish have brought the language of "space" and "place" to bear on this distinction [8]. Manually, we divide up each camera's image into rectangular zones, which we call semantic activity zones (SAZs). Each SAZ represents a person-sized social "place", which results in a a set of 30-50 small zones. Conceptually, rooms are also semantic "places" and may composed of multiple be sum of the SAZs they contain. We name the rooms dining, living, kitchen and transit, capturing movement areas (though TM does not internally represent any social distinctions between them).

We build a graph out of the zones, connecting contiguous zones. We connect two zones if there is a way for a person to move between the two zones without passing through a third zone. This connected graph of rectangular spaces defines a particular topology of the home. For our study,

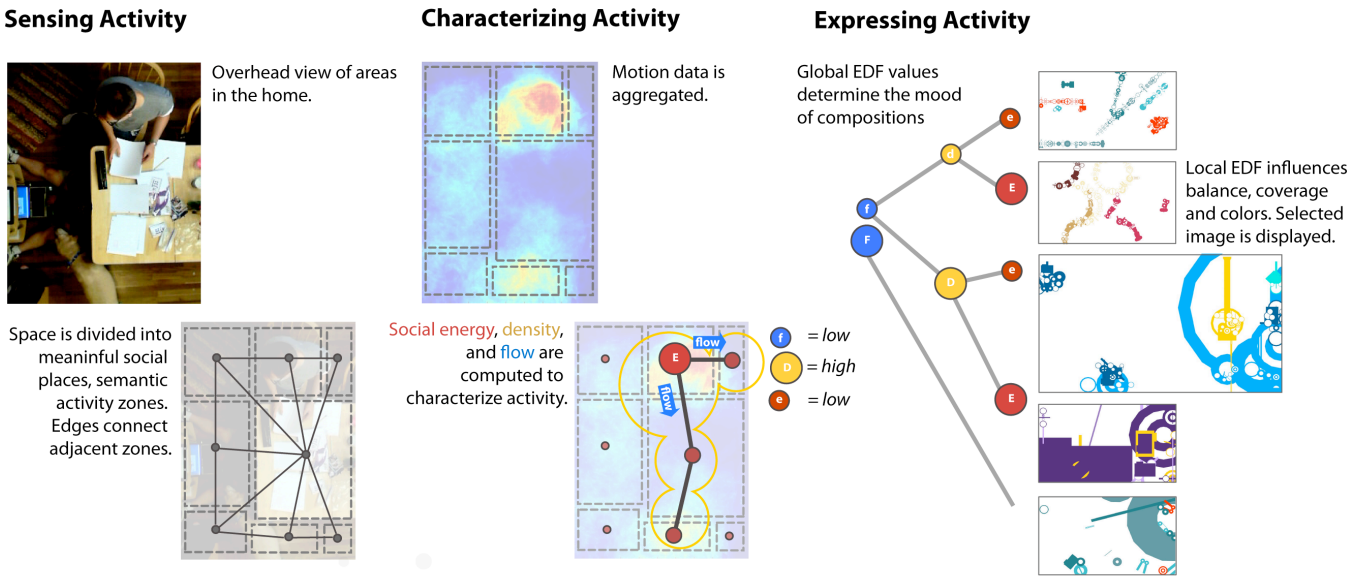


**Figure 2:** TM has three modules, a sensor, an characterizer which interprets motion and activity, and the expression system, which selects and adjusts images. Overhead cameras sense motion. The characterizer measures social energy, social density, and social flow. The Expression system contains a generator which creates 5 different regimes (from delicate and curving to angular and wild) of TM compositions. Local EDF values influence visual balance and percent coverage and then the final image is colored and displayed.

we assume the topology does not change (though it would change if, for example, householders rearranged the living room, or undertook renovations).

### Characterizing Activity

TM does not just present raw data to householders. We use the raw data aggregated over 20 second time windows to generate a characterization of the whole house (and each room and zone) at any moment. Some examples of characterizations or moods in the house that we want to sense include "a movie night with friends," "a mopey dinner" or a "charged argument."

We want to stress that capturing the character, or said another way, the mood or vibe of the home, is ambiguous and subject to varying sensitivities and interpretations, even if it is done by human beings. Two different people might come to different senses of the character of home life at a given moment. Activity characterization is different from activity recognition, in that it succeeds or fails based not on objective truth, but on a co-created agreement between the subjects (householders) and an observer (Tableau Machine).

We identify three dimensions of social life that help us to convey a characterization of life in the home. ***Social Energy*** is how much aggregate motion is present in a SAZ, room, or in the entire home. Charged household disagreements, or dancing, create more motion than leisurely times. ***Social Density*** is a measure of how closely packed the energy is in space. Social togetherness is not always spatial togetherness, we note, but often being nearby in space makes for a common social space. A family dinner is a situation with high social density. ***Social flow*** captures a sense of the streams that make up householder activities large and small. An example of household flow is, for example, moving after dinner to the kitchen for clean up. In prior work, Romero et al. define the three social measures and their calculation [15].

### Expressing Activity

The expression subsystem generates an endless array of machine-like compositions, made up of a set of structural forms, like gears, blocks, bars, and smokestacks. We strove for viewers to read the compositions as geometric, colorful, and reminiscent of a machine. The expression system has three levels which influence the look of each composition. At the top level, there is a decision tree that selects the large-scale 'mood' of a composition by selecting a shape grammar (see Figure 2). High activity causes TM to select very busy and angular designs, while low energy but densely packed situations produce delicate curving designs.

At the second level, local values of social energy, social density, and social flow, along with the computer's clock time, are used by the generator to determine composition attributes, such as color palette, how well balanced or off-kilter the composition is, and the coverage, how much of the composition is filled with shapes. These local values of energy, density, and flow are clustered; each home's clusters move through the production space, capturing the regularities of different homes while still generating new compositions each time. Smith et al. presents further details of the generator [18].

Because we sought to defamiliarize the home and to support open interpretation by householders, TM images may not be meaningful at the outset. Only through long exposure to the stream of images do coherent stories start to emerge. TM produces a continuous stream of images, and householders can press a key on a keypad in order to print out the current image. In this way, images can be saved for later reflection, and comparison with others that are produced.

As we deployed preliminary versions of TM, we found that we needed to design more direct interpretative hooks so that householders would recognize that TM generates representations based on observed activity. Our original refresh rate was minutes long and fixed. As a simple hook, we created a special zone, a SAZ immediately in front of TM. When there is motion in this zone, TM responds by refreshing images at a fast rate of once every five seconds. The special zone is where householders can get "in its face" and force TM to create more images.

## FIELD STUDY

In order to explore the degree to which our design choices matched our goals of supporting and encouraging reflection and contemplation, we deployed TM into three homes in the Atlanta area and analyzed their activities with TM.

### Procedures and Methods

For ubicomp systems that have interaction patterns that are not known in advance, a longitudinal investigation is required; we cannot know in what ways (or even if) households will appropriate technology until they have it for long enough for appropriation to take hold at the day-to-day level. We recruited three homes from posts to a local online message board (http://www.craigslist.org) and TM was installed for a period of six to eight weeks.

| | Household A | Household B | Household C |
|---|---|---|---|
| **Parents** | Andrew 40s (technologist)<br>Amanda, 40s (stay-at-home mom) | Byron, 40s (co-owner of daycare with spouse)<br>Betty, 40s (co-owner) | Carla, 30s (translator) |
| **Children** | Alice, 10<br>Andy Jr., 5<br>Amy, 7 mos. | Brian, 14<br>Brianna, 10 | Charlie, 10 |
| **Pets** | Large dog | None | Two cats |
| **TM** | Broken (see below) | Functional | Functional |

**Table 1:** Names have been changed to protect each participant's identity. Householder's first initials match the household code (e.g., *Byron* lives in household B).

We selected our households on a variety of factors, but we intentionally chose households that contained children living at home, because families with children have two attributes of interest. First, we speculated that households with children would be busier than houses without children, and we were interested in finding homes with lots of social states and configurations from calm to outright frenetic. Secondly, we were interested in feedback from a wide population of users and we felt that children might engage with TM differently. Households A, B, and C are described in table 1.

With systems that are intended for extensive interpretation and appropriation by users, there is a challenge of how much to divulge to them, both about the research questions and about how the system works. Being too evasive can lead to suspicions on the part of users (see [7] for an account of this), but being too open can unduly influence the participants as well. In early conversations with families, we framed TM as *"watching what you do and creating pictures from it"* but we did not explain specifically how household activity changes the images, hoping that participants would discover these connections. We described the system as an art piece, and as a tentative technology that we wanted to improve. We told households that they might like *"getting a different view of their houses"* but, in order not to influence the households, we did not explicitly talk about co-interpretation, or that we intended TM to support household reflection and contemplation in order not to influence the households.

#### *The Broken Tableau Machine*

Household A received a TM that was different from the others. Because we misconfigured the system, TM appeared to work; the camera data was captured and images were created. However, the data from the cameras was never read by the expression subsystem. Instead, the expression system read from an empty file, and produced images influenced only by the computer's clock but that were otherwise random.

We discovered this problem on the final day of the deployment at Household A, just as we were beginning to dismantle the system. Our interviewer did not have any inkling that something was technically wrong, though he did find that the family was less engaged with TM. We discuss this in the following section, but the Household A deployment does serve an important check against one potential problem with studying systems designed for open interpretation. Will people, when shown random or pseudo-random outputs, still engage in deeply interpretation and engage it? If all of the interpretative work is being done by the human participants, without any active understanding or interpretation on the part of the system, there is no point in developing a complex computational infrastructure. Though this is investigation is not an experimental control by any means, the differences between a broken TM versus a correctly functioning one highlight that co-interpretation led to deeper engagement in the analysis section below.

### Interviews and elicitation techniques

Our investigation was qualitative in nature. We sought rich accounts from family members about the rhythms and activities of the home, both in pre-installation interviews and in periodic (approximately weekly) interviews at the home. In addition to **qualitative interviews**, we used a small set of elicitation tools during the interviews to support both retrospective stories of home life and reflection and conversation around TM.

A **feltboard** is a tangible representation of a set of objects or interface elements and participants can move around the pieces on a board, either individually or as a group, to tell stories or to design a configuration [12]. We built a feltboard representation of each home we created tokens for furniture (including a TM token) and little figures representing the householders. Using a feltboard helped to improve recollections of activities or the recounting of a particular story.

We deployed a **word game** with householders near the end of the investigation. We presented a big set of words, each printed on a strip of paper, and spread them out before the family. Each individual was asked to select a small set of words that might describe salient aspects of TM. It included words about the physicality of TM ("screen" "camera"), the productions ("circles", "lines"), metaphorical ascriptions ("blender", "thermometer", "mirror") as well as judgments ("boring", "engaging", "befuddling"). The word game also included freeform blanks for householders to fill in.

**TM Printouts** became one of the most salient mechanisms for getting feedback from householders. Householders could easily print images they liked (or wanted to write on, or for any other reason) via a small keypad. Often, in a week, families would have created a stack of images and they would spontaneously suggest that we go through all of the prints they made.

### Analysis

#### *Trajectory of Appreciation*

Gaver *et al.* describe the adoption of a new technology as following a trajectory of appreciation [5]. In Gaver et al.'s trajectory of appreciation, at the outset, a new technology is embraced merely because it is novel to users. These novelty effects wear off, as functional limitations, fragility, and problems become apparent, which can even bring satisfaction below its original state. This happens when a task or activity is made more difficult and less satisfying by the introduction of the device or technology. After weeks or months the technology settles into a steady-state of use. Either the technology is rejected, or it is adopted, and usage and satisfaction rise. Users find ways to route around the difficulties they might face and to use the technology in spite of its limitations.

A longitudinal analysis of appreciation is particularly applicable to TM, since TM cannot be fully understood, much less appreciated, in a few minutes of observation. As such, watching the trajectory rise and fall is instructive as to how well or how poorly the system becomes integrated into the lives of householders.

*Experimentation with Tableau Machine Inputs / Outputs*

Householders universally began with a sense of bemusement or puzzlement. Brian stated *"How can you tell what's what?"* (note: Names have been changed, but each name's first initial matches the household code, so Brian, a 14 year-old young man, lives in household B). Andrew, a professional engineer claimed at an early interview that he had performed an "experiment" with TM. He described it thus:

> Andrew: No pictures are ever two the same. I've already tried to do that.
>
> Interviewer: Is that right? You tried to do that? How did that work?
>
> Andrew: ... So yeah, no, there was no one else in the house. So I just sat right here and I was just [he mimes holding still], and I was looking at it and looking at it and... But I could never get it, the same exact image. ...
>
> Well that's what I'm trying to figure out, If it's taking numbers, images, from [the cameras], then why is it not the same picture every time? You know?

With TM, even if the system inputs are the same, different images will be generated, though they will share the same style. This would not be apparent after just a few days.

While none of the B and C householders are scientists or engineers, they also reported performing experiments to figure out how TM works. Some of these experiments were individual activities while others took more than one person to perform. Early on, Carla wrote on a particular image, *"Question: I wonder if different colors in the rooms -- in front of the cameras will produce different colored art work? Something with different motions -- harder to quantify, I think."* (Carla)

*The Endpoints of the Trajectory of Appreciation*

In household A, with the broken TM, participants were unable to develop rich stories about or form long-term attachments with the system. The logic by which the TM mapped home activity to images was impenetrable, since there was no such logic. This caused householders to give gave up on TM, and they were dismissive of TM as the deployment wound down, though they . Householders were proud of their discovery that the TM had patterns of colors and compositions that differed between mornings and evenings. They claimed that certain collages were *"morning ones"* and others *"evening ones"* based on colors and composition attributes that were influenced by the computer's clock (the clock was the only variable influencing the images of broken TM). But the family did not draw deep meaning from the relationship between morning and evening images and the differences in the home at these times.

Household A, in the word game at the final interview, selected simplistic words to describe TM and were neutral as to their experience. Alice even selected the word "stupid" to describe TM, while other family members were more charitable. Amanda selected "confusing" amongst other words.

In contrast, households B and C, with correctly functioning TMs, stayed quite engaged with TM throughout the full six-week deployment. While these two conditions for TM (broken and functional) were unplanned, they formed a kind of natural experiment into the dynamics of co-interpretation. A question for designs that employ co-interpretation and ambiguity is whether *any* strange device you might put into a socio-cultural context would evoke interesting interpretations, precisely because all the work is being done by the participants (all human interpretation, rather than co-interpretation), rather than the system. If this were the case, there would be a real sense in which the system design is irrelevant, and for which the only design rubrics is "do something strange and ambiguous". Our natural experiment shows that this is *not* true, that active interpretation on the part of TM, and thus true co-interpretation, supports a significantly deeper experience for households B and C.

Household B stayed engaged with TM. They found that the productions were very much *about* the family. Near the beginning of the deployment, B2 (the mother) began to describe images as being views of the house, either from above or from other perspectives. Other householders followed along in this reasoning, and pointed out clusters that were *"the kitchen table"* or *"the hallway."* As the deployment progressed, B householders began to see individuals in the images, and to draw parallels between activities (such as a boisterous dinner) and the images (a large round shape full of messy shapes on top, including a set of lines that formed something resembling a fork). The family was quite enamored with this image, and others that represented moments around the house. In the last week, Betty found an image that looked like a smiling face, which she took (or pretended to take) as an image of her husband cooking at the stove. At the interview she was very proud of the printout and asked if she could keep it. She hung this picture on the refrigerator.

Household C ended with feelings of intimacy toward TM. Our impressions come from two occasions where householders did something special with TM. As we tore down the TM, we noticed a particular image that had been written upon by Carla. She smiled, and was very excited about the printout, and asked if she could keep it, along with all of the TM images. We asked what she might do with them. Carla replied that she wanted to make a photo album of TM images, alongside images of the householders. She said, *"You know how you put in pictures of a vacation? These will be pictures of when Niko [their name for TM] was living with us."*

There are two interesting parts of her answer that give us confidence that she was creating more than a casual connection to TM. First, the C household's experience with TM is memorable and positive enough to warrant the investment of time and money to make the photo album. Second, she described the TM system as having a social presence in her home. The family felt differently about the home when "Niko" (TM) was deployed there, and wanted to remember that time period.

*Hints of personality*

Householders attributed some personality to the TM. The TM computer at household A crashed at one point during the deployment and the father was around as we rebooted the machine and restarted the TM software. Even though the TM had no data from household activity, the TM had adapted to the household by clustering the space of possible image styles around the only data it had available – the system clock. When the TM crashed, all of these cluster centers were lost, and the TM started again with randomized cluster centers. The new images were strikingly different from what the family had been seeing the last few weeks. Andrew described it, *"Wow those are the old ones [dark green, blue, purple, maroon]?! ... That's what it looked like when we started, like an infant. ... [it had] more shapes inside other shapes."* He interpreted the simple compositions as being childlike and simplistic, while in contrast the images he had been seeing for the past weeks had been more complex and delicate. Andrew interpreted this as the TM growing up (and the crash had reverted it to childhood).

Household C also provided evidence of ascribing personality and aliveness to the TM. At one point, 10 year old Charlie had his mom buy him an embossing labeler, which he used to label people and animals in the house. Carla, Charlie, and Charlie's friend, who was over for the afternoon, were all labeled with their first name on their forehead. Charlie then labeled the two cats, and, interestingly, labeled the TM screen with "Niko" (Niko was the brand of flatpanel TV we provided with the TM). He did not provide a name label for any other technology artifact in the house, including the main TV, his videogame consoles, or any of the computers in the house (he did eventually label his personal laptop). The family referred to the TM as "Niko" from then on, and came to treat it as a social presence living in their house (as described above).

*Printing Practices*

Householders, both young and old, printed many more images from TM than we originally expected, printing images that they liked, or that they wanted to comment on, or that were *"new"* (i.e., they showed a previously unseen color palette, or a previously unseen shape grammar). Even though printing in the A household was limited, Alice still claimed that she enjoyed the printing activity, stating *"I might as well just print a couple pictures. And by a couple, I mean ten thousand."*

Household A, since they engaged less with TM overall, printed less frequently as time went on (average of 1.46 prints per day). In the B and C households, printing activity was frequent throughout the deployment (average of 3.16 / day and 12.64 / day respectively). The C house was particularly enamored with printing; on a couple of occasions, they printed over 100 images per day, and sometimes 8 or 10 images per minute.

Printing in the B house occurred usually in gregarious times in the afternoons and evenings, when many householders and frequent guests were present. Printing in the C house covered more times of day and social as well as alone time (Carla worked from home some days and printed images as she took breaks, cleaned, and cooked).

*Deepening of reflection*

One of our design goals is for TM to be a resource for reflection. We hoped that the constantly changing stream of imagery, correlated with household activity, would help make the invisible patterns of the household visible. We found evidence TM did become a resource for reflection, though household members did not learn to interpret stylistic features of individual images such as coverage in terms of household activity, instead reading meanings into colors, the overall composition, and individual shapes.

As the other families lived with the TM, they began to find ways to integrate it into their routines and rhythms. In the morning, as householders got ready for the day, many family members glanced at the TM as they went about their routines, printing many images during this time. Betty described the TM's pale colors and slow refresh rate as mirroring her morning thoughts. She said, *"You think about all the things you're going to do."* She contrasted this with the images in the evening times, where the colors were *"vibrant,"* and *"happy... In the evenings we're happy, since we did a good day's work."* (Betty)

Some householders reported being mesmerized for a long moment watching the TM. Alice reported watching the TM instead of television, as a kind of *"show"* analogous to a television program (though household A's TM was broken and this behavior was abandoned later). Betty noted a time when she was home alone and was *"trying to make myself go up[stairs]"* but wound up watching the TM refresh a few times first. These moments of doing nothing, just "puttering" around the house, were moments where the TM became a salient resource for the unstated and even unconscious reflection on home life.

Toward the end of the deployment, Carla came home one day after her workday ended (in the early morning, so she was very tired). TM produced an image that looked like a *"bunny rabbit"* to her, and the bunny was looking out at her. She found this comforting and cute, and wrote on the image *"I just got home from work. This looks like a cat or a bunny rabbit. I feel like it's a face greeting me"* (Carla).

In household B, a particular image appeared late in the deployment that was part of a happy moment at home. Late one evening, Byron was cooking in the kitchen and Betty was keeping him company. She walked out into the living room and an image appeared on TM that looked like a smiling face. She laughed and made of big deal of it at the time, and wrote on the image *"Face of my husband. In the kitchen cooking. Apron."* (Betty).

However, people did not always find relationships between images and activity. During an interview in household B, we asked about images that had been printed during an afternoon when cousins had come over to play videogames. When asked by the interviewer "*Does this [image] look like video game playing?*, householders, both those involved and those watching, said no. Similarly in household C, Carla recounted a recent evening where

Charlie had done poorly on a math test, and Carla spent the evening helping him correct his work. It seemed like a tense time, so the interviewer found an image of that time and asked "Does this look like homework?" Charlie replied that it did not.

While TM did succeed, to some degree, in becoming a resource for reflection, households did not create vocabularies around the TM for describing the dynamics of everyday life. The "homeworkyness" of an evening or the "videogameness" of an afternoon still remained opaque. While individual TM images would occasionally open up a moment in the home to deeper reflection, the family did not develop systematic social methods for doing so. There were interesting hints that TM images themselves began becoming a proto-language for describing everyday life dynamics. During several interviews, householders, when describing a particular episode in the home, would flip through their printouts of TM images to describe a household moment as *"being like this [pointing at an image]"*.

### *Feelings of "Being Watched"*

In all three homes, some participants, at some points in time, felt watched. We expected to find these feelings amongst householders, and were surprised that they were mentioned so infrequently. Most of the time, the TM's cameras went unnoticed or at least unremarked. We were very careful to explain how the TM worked at the outset. During the pre-installation interview, we stressed to householders that no camera images were stored—they are analyzed and immediately discarded.

That being said, the conditions under which participants did report feelings of being watched were interesting. In all households, adult women reported feelings of unease in some situations. Mothers in houses A and B recounted feeling like the system was watching them as they walked around their downstairs areas late at night. Betty mentioned specifically her pajamas and whether her body position would expose her to the cameras. Amanda mentioned eating a late night snack of ice cream in the kitchen and feeling like the system "might tell on" her.

In the C household, feelings of being watched were less pronounced. Carla reported "making sure" she was dressed appropriately before coming downstairs in the mornings to make coffee. Charlie also mentioned that he called the overhead cameras "the spies," stating:

> Charlie: [pointing up] "the spies"
>
> Carla: "Yeah, he calls it 'Niko and his spies.'"

## DISCUSSION

Returning to our goals, we strove to create a curious and not-immediately-understood artifact that provides a novel and engaging window into everyday home life, creates a sense of social presence (personality), is engaging over a long period of time, and becomes a resource for conversation and contemplation on the rhythms and routines of the home.

For households B and C, TM succeeded in being engaging over the entire period of the study. This is markedly different from household A, whose household engagement, printing activity, and interest waned. Our accidental misconfiguration of TM for household A allows us to compare purely projective interpretation (all the meaning found in TM comes from the family) and co-interpretation, where TM actively participates in meaning making. Household A's failure to, in the long term, incorporate TM into family life provides powerful evidence that the success of TM is not purely a function of humans being able to read meaning into almost anything (a Rorschach effect), but rather that TM's active interpretation and generation support human meaning making.

Even in successful TM households, families had some trouble describing the mood or character of their homes, the very thing that TM is about. While there was some evidence of TM providing a resource for reflection (described above), their descriptions of activities, events and rituals around the home were primarily factual reporting. It may be that the "fine art" nature of TM made it difficult for families to bootstrap a language for talking about the home. Our families also had difficulty verbally describing TM compositions. They did not readily come up with design-focused descriptions of TM images such as "balanced/unbalanced," "sparse," or "juxtaposed." They used simpler words like "vibrant" and "empty/full"; this may have prevented them from remembering or even consciously noting some of the distinctions in TM's image space (remember that TM maps distinctions in home activity into distinctions in the image space). It would be interesting to deploy TM in a household that includes artists, designers, or art historians to see if this results in TM becoming a deeper resource for reflection.

One limitation with TM is that householders experimented on the timescale of a few seconds or at most a minute (children often waved and adults had their "experiments"). But since TM aggregates motion data, these experiments were often unnoticed by TM. While the process of figuring out TM was a long term activity, it took place in very short bursts of reflection and experimentation. TM did not support these experiments by immediately noticing and responding to householders.

## IMPLICATIONS FOR SMART HOME DESIGN

### *Sensing the character of activity*

Ubicomp systems often sense the environment to support an activity. Our work on Tableau Machine suggests that sensing features that characterize an activity, instead performing categorical "activity recognition", allows for inexact but still useful measurement. For problems where activity classification and precise tracking may not be required, sensor-based characterization provides a tractable alternative.

Activity characterization could be used to report on the status of a baby in a crib, without attempting to recognize (perfectly) whether a given motion is a yawn or stretch or a scream. It could be used to provide insight into the

developmental trajectory of an autistic child. We hope that ubicomp designers will continue to explore alternative notions of sensing that can impart information about everyday dynamics.

### *Cameras in the home*

We were very explicit in our discussion with householders regarding how TM uses camera data. In our deployments of TM, households were able to accept and even forget about the cameras for most social situations.

Those situations in which cameras raised red flags imply two important facts for design teams installing sensing technologies in the home. First, different householders will have different reactions to invasive sensing; in our study, women were more sensitive than men. Second, alone time, even in social places in the home, is more sensitive than social time. Ubicomp researchers may want to use the system's sensors themselves to change the recording based on which householder is in the sensor's view. Shifting between fine-grained and coarse sensing for some situations and social exchanges might be a profitable way forward for potentially "invasive" sensing.

### *Enhancing Experiences with Co-Interpretation*

Users are naturally curious and playful. This curiosity extends beyond the first few hours or days and can be extended through careful design. Users' interactions with a ubicomp system (and feelings about it) will change over a long-term deployment. Paying attention to the playful and experiential aspects of a system can help it to become a fixture in the home.

Co-interpretation need not be restricted to playful and artistic systems, but could be used to enhance task-based systems as well. For example, a cooking support system could help users experience differences in the felt-life of cooking (hurried vs. leisurely, social vs. alone) while also providing task support.

### *Mental models and experimentation*

Ambient intelligence systems should support rapid experimentation by household members. We found that families actively experimented with TM to more deeply understand the system. However, these experiments were only a few seconds to a minute long; the longer time scale on which TM responds to activity made it difficult for families to perform successful experiments. Ambient intelligence systems should have interpretive scaffolding modes that support active experimentation by responding to short-term activity.

### *Printing as system feature and investigation aid*

The ability to print system states was a successful feature in TM. It worked both as an engaging activity for householders and as a way to evaluate and analyze householder reactions. Even in task-based software, printing of system state can be great way to understand what is not understood by users, as well as to get rich accounts of what they were trying to do at that moment. The prints served as a memory aid to reconstruct the situation, as well as a souvenir. Participants were more than willing to write on the printouts, denote important or strange parts, or describe their intentions and questions.

## RELATED WORK

In this section we compare Tableau Machine to other systems that characterize activity, as well as systems that support experiential, ludic, and reflective goals.

### *Characterizing Activity*

The Perceptive Presence work of Bentley *et al*. is a system built for the workplace that can inform distant parties about the activity of remote collaborators and colleagues [3]. The system displays presence and activity via a matched set of glowing ambient lamps. Like TM, Perspective Presence uses computer vision to monitor activities across socio-spatial zones; however, TM uses this information to feed a higher-level interpretative and generative process, rather than directly visualizing this data.

In the domestic arena, the Digital Family Portrait (DFP) of Mynatt *et al.* [13] displays a single household activity metric on a picture frame border. Adult children of geriatric family members hang the DFP in their home or office and monitor the activity of the senior family member. In contrast to TM, DFP directly reports a single activity measure, rather than mapping more complex activity distinctions into a rich and expressive image space.

### *Reflective and Ludic Technologies*

The History Tablecloth, an electroluminescent tablecloth, contains pressure sensors that measure the weight of objects that individuals place on the table [6]. The table glows in a halo around objects, and the halos remain, leaving a ghostlike trace. Like TM, this system aims to make visible the dynamics and history of household activity, though limited to activities at the table.

Viegas *et al*. created *Artifacts of the Presence Era*, an interactive installation for art galleries [21]. Artifacts transforms sensed video and audio from the gallery into a single "postcard" that displays distorted video frames influenced by the sound levels in the gallery space. Similar to our work with TM, viewers could print these souvenirs and found this feature to be a compelling (even addictive) part of the system.

Closer to our work, the Home Health Horoscope (HHH) monitors the state of a small set of sensors placed in the home. Each morning, HHH generates a text-based "horoscope" [7]. The horoscopes are reconfigurations of a corpus of phrases from real newspaper horoscopes, and are designed to reflect the state of the home as modeled by the sensors (the sensors were placed around the home after an ethnographic study of the home and family).

The home into which the Home Health Horoscope was installed read the horoscopes frequently, but had some trouble making sense of their ultimate meaning, thinking that perhaps the experimenters were trying to trick them. Engagement waned in the later weeks of the deployment, partly because householders decided that the horoscopes were only for the mother of the house.

TM has a more general sensing infrastructure than HHH, designed to find distinctions in household activity, rather than map specific sensor values into specific household states. The TM also maps activity into a very public visual representation, which, because of its genre (abstract art versus a horoscope paragraph), allowed for more happy accidents of interpretation. Horoscopes may not have allowed for the ambiguous and wildly interpretable statements produced by TM compositions. We feel that co-interpretation requires a large interpretive space to be successful. A final distinction is that TM produces images frequently and this matches the frequent shifts in activity and mood throughout the day, compared to the once-per-day statements in HHH. Generating images frequently may have helped TM to seem more like a conversation, instead of a pronouncement.

## CONCLUSIONS AND FUTURE WORK

We have presented the design and a longitudinal study of Tableau Machine. TM senses human activity and generates cryptic images that provide a characterization of life in the home. Householders experimented with the system, and found TM valuable when it described or commented on certain social situations, capturing something "right" about home life. TM opens a wider design space for the sensing of human contexts, showing that valuable interactions can be produced from ambiguous and imprecise metrics.

We plan improvements to TM to support the kinds of active experimentation we saw. We also plan a longitudinal deployment of TM into non-domestic spaces, including office lobbies, coffee shops and museums.

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