Eccentric Sensing Devices

Using Conceptual Design Notes to Understand Design Opportunities, Limitations, and Concerns Connected to Digital Sensing

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Abstract

More things are becoming equipped with digital sensors, central processors, and network connections. Alongside marketing and engineering terminology such as Internet of Things and ubiquitous computing, designers and HCI researchers need new concepts to help understand the design opportunities, limitations, and social concerns connected to digital sensing systems. This pictorial presents an array of conceptual design notes clustered around 5 themes: sensor overreach, layered sensing, floating sensors, upredictable sensing, and sensor attenuation. Reflecting on our creative process, we articulate the methodological concepts of eccentric devices and conceptual design notes. As a whole, this pictorial exemplifies the value of intimate and nuanced depictions of creative processes—details too often omitted from final publications and finished products.

Authors Keywords

Design research, research through design (RtD), smart home, Internet of Things (IoT), privacy, speculative design

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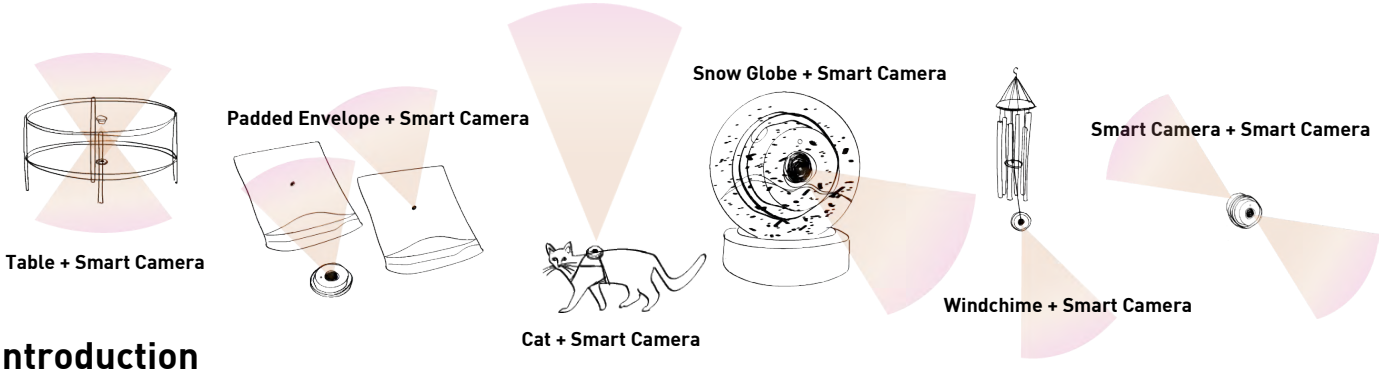


Introduction

Every day, it seems, more and more things are equipped with digital sensors, central processors, and network connections. Smart cars, smart watches, smart doorbells, and smart speakers represent just a few of the ordinary everyday things now embedded with Internet-connected, computational sensing systems. Current consensus portends a future with even more specialized, diverse, and numerous things that sense—glasses, furniture, bridges, mirrors, toothbrushes, and even toilets [28].

In order to make sense of this situation, engineers use terms such as ubiquitous, minitiarized, distributed, and autonomous to describe digital sensing devices. Marketers use terms like smart, connected, and IoT (Internet of Things). Alongside this technical and business terminology, however, we need concepts to help designers and HCI researchers better understand and craft the experiential and practical qualities of these so-called smart, ubiquitous, IoT sensing systems. We further need concepts that enable us to address emerging social and ethical implications of sensing technologies, ranging from explosive cultural flashpoints such as facial recognition [3, 6] to more mundane situations such as smart camera social etiquette while housesitting [26].

Smart sensing devices can enhance human creativity, productivity, and meaning-making. But they also introduce and exacerbate concerns with surveillance, privacy, security, and data ethics. A central premise of this project is that speculative and experimental design approaches can be used to divergently and obliquely investigate these issues and yield insights that a more direct problem-solving approach will overlook.

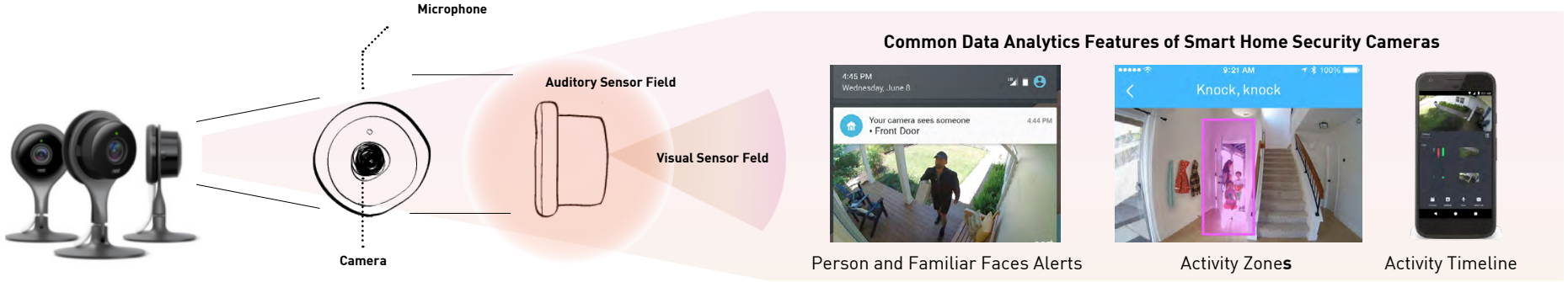
This pictorial presents a design inquiry that investigates opportunities, limitations, and social concerns connected to everyday sensing systems. The primary contribution is twofold. First, this pictorial presents an array of novel conceptual design notes for understanding, crafting, and addressing smart sensing systems. These concepts are loosely organized around 5 themes: **sensor overreach**, **layered sensing**, **floating sensors**, **unpredictable sensing**, and **sensor attenuation**. Second, this pictorial demonstrates and generalizes our design approach through the methodological concepts of **eccentric sensing devices**, **product redirection**, **anchored speculation**, and **conceptual design notes**. These approaches contribute to broader discourses on creative practice spanning design imagination [12,14, 40], design methods [7, 15, 19, 37], and design as a mode and outcome of research inquiry [16, 35, 24, 36].

Prior work has shown how speculative and experimental design approaches can yield concepts useful for identifying trends, articulating insights, (re)framing problems, and proposing design responses [e.g., 4,18, 22, 29, 30, 31,3 2]. Some of the ideas presented here have been reported in the author's prior work [29, 30, 31, 32], though the vast majority of the text and images in this pictorial are novel and previously unpublished content. This pictorial forms a space to present a clustered array of conceptual design notes that don't readily fit within the linear flow and format of a traditional research paper. It further presents an opportunity to articulate underlying methodological approaches that emerge from and inform our prior published research in this area.

Too often the "intermediate" design outomes of creative practice contained within notebooks, workbooks [41,42,43], and studios are abandoned or discarded in favor of a "final" refined and singular object. Here we amplify and elevate intermediate design proposals, scenarios, and experiments into a refined compositional whole using conceptual design notes: figures that integrate written ideas and design things. Conceptual design notes form the glue which holds this composition together. These conceptual design notes merge the creatives practices of generating ***design concepts*** and ***conceptual writings*** about designs, and blur common distinctions between a design drawing, proposal, scenario, prototype, and product.

Design Inquiry: Focus, Approach, and Structure

This inquiry focuses on smart home security cameras such as the Google Indoor Nest Cam and Amazon Cloud Cam. These devices are, in fact, more than cameras and more than security devices. They contain microphones, advanced analytics features such as person recognition, and are often marketed and used in ways that extend beyond traditional security applications, including monitoring pets, kids, guests, and nature.



Approach Part 1: Eccentric Sensing

In contrast with design methods involving a linear set of formalized steps, our approach is organized more fluidly around a set of sensitizing concepts. These concepts have emerged iteratively through the course of this project. We elaborate and reflect with finer resolution on each of these methodological concepts in the concluding section of the pictorial:

- *Eccentric sensing devices*. We devise unusual devices guided loosely by the aims of exploring design opportunities, limitations, and concerns connected to sensing systems.
- *Product redirection*. We use off-the-shelf consumer products and everyday things as design materials and components.
- *Anchored speculation*. We ground our socially and experientially imaginative design leaps by using existing technological consumer products as material constraints and salient features.
- *Combinatorial designs/variations.* We use a simple algorithm to generate designs: smart device + everyday thing = eccentric device. (See Page 1 for examples.)

Focus: Smart Home Cameras as Design Material and Conceptual Lens

Smart home security cameras form the primary building blocks for our eccentric designs. We use existing consumer smart cameras as design materials by creating unusual product accessories and extensions that amplify, restrain, and deviate current features and functions. We focus on smart cameras for multiple reasons. Smart cameras represent one of the most popular and growing areas of smart home technologies. In addition to conventional image-capture, when combined with cloud-based or onboard image/video data analytics, smart cameras can perform advanced tasks such as motion detection, facial and object recognition, location estimation, dynamic masking, and even emotion tracking from facial analyses [8,11,34]. For these reasons among others, smart home cameras prove highly generative and illuminating focal points for understanding camera sensors and image/video analytics specifically along with connected sensing systems more broadly.

Approach Part 2: Conceptual Design Notes

Conceptual design notes represent a second novel aspect of our design research approach. Conceptual design notes are a way of conducting, creating, and presenting design inquiry wherein design concepts and conceptual writing merge. As prior work has argued, designing things can be a way of understanding situations and developing ideas [16,2430]. This way of practicing design as inquiry typically yields very different outcomes than design practiced within a commercial or product development context. Rather than presenting a single refined prototype or a small set of key takeways, we present a constellation of conceptual design notes clustered around 5 themes: sensor overreach, layered sensing, floating sensors, unpredictable sensing, and sensor attenuation. Each theme provides a handhold for grasping design opportunities, limitations, and concerns connected to smart sensing systems. Each conceptual design note (titled bodies of text with images) form a multi-functional tool that may variously be used to understand an issue, appreciate a current trend, frame a new problem, or design a new thing.

Layout and Structure

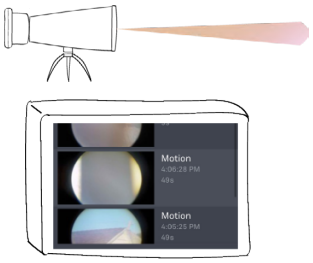
Each theme is introduced with a set of simple, diagrammatic eccentric sensing devices. The devices and themes are then briefly explored through some combination of material experiments, performative props, operational prototypes, and self-use studies [12]. We conclude with a single condensed page of notes focused on addressing privacy, security, and data ethics challenges, follow by a single page reflecting upon our approach and the formation and use of conceptual design notes.

The layout and structure of this pictorial serves two core aims. First, this pictorial presents a **detailed sample of our extensive work developing eccentric sensing devices and conceptual design notes**. Second, this pictorial is designed to **reflect the emergent and exploratory aspects of design inquiry and invite the reader to forge novel connections and partake in flights of imagination**. We aim to foreground the layered meanings, fragmentary insights, and circuitous pathways traced through design inquiry. In doing so, we aim to present a view into our creative process and the creative design process generally.

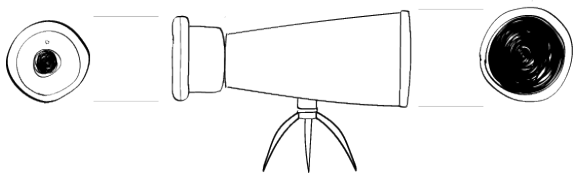
Sensor Overreach Devices: Smart Cams + Telephoto Lenses

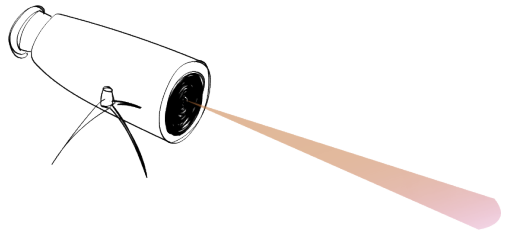
While the resolution of consumer smart home cameras has improved, further enhancements could greatly expand the perceptual powers of the smart camera gaze. Adding a telephoto lens to a consumer smart home camera not only improves the image quality of distant subjects. Optical amplification also extends the capabilities of data-analytics features such as motion detection and facial recognition. *With this extended sensor reach come concerns over social* **overreach**.

Eccentric Sensing Device Pattern

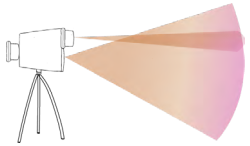


Version 1: Single Telescopic Lens + Smart Camera. Affixing a telescopic lens to a smart camera extends the range of the sensor field. This likewise extends the range of analytics features. For example, the user may receive a notification whenever motion is detected, a known or unknown person's face is recognized, or a certain activity is detected, such as opening a door or a commotion. The detection of emotions and objects is also possible.



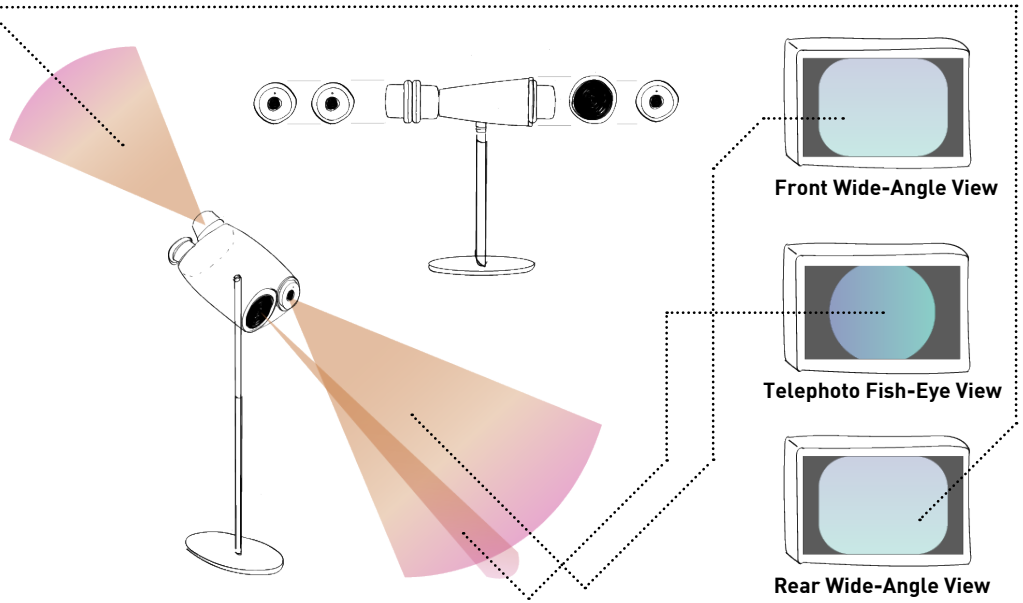


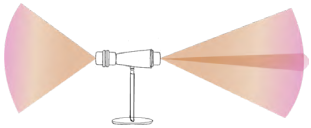
Tele-Portal View. Most visual displays are rectilinear. The spherical telephoto view invites a fresh look and unusual gaze. It also reinforces the view of the device as a portal into a distant place. A standalone display further accentuates an eccentric, portal-like perspective.



A distant subject *The subject's context*

Version 2: Version 1 + Wide Angle Lens. Adding a second wide-angle lens provides a contextualizing viewpoint.



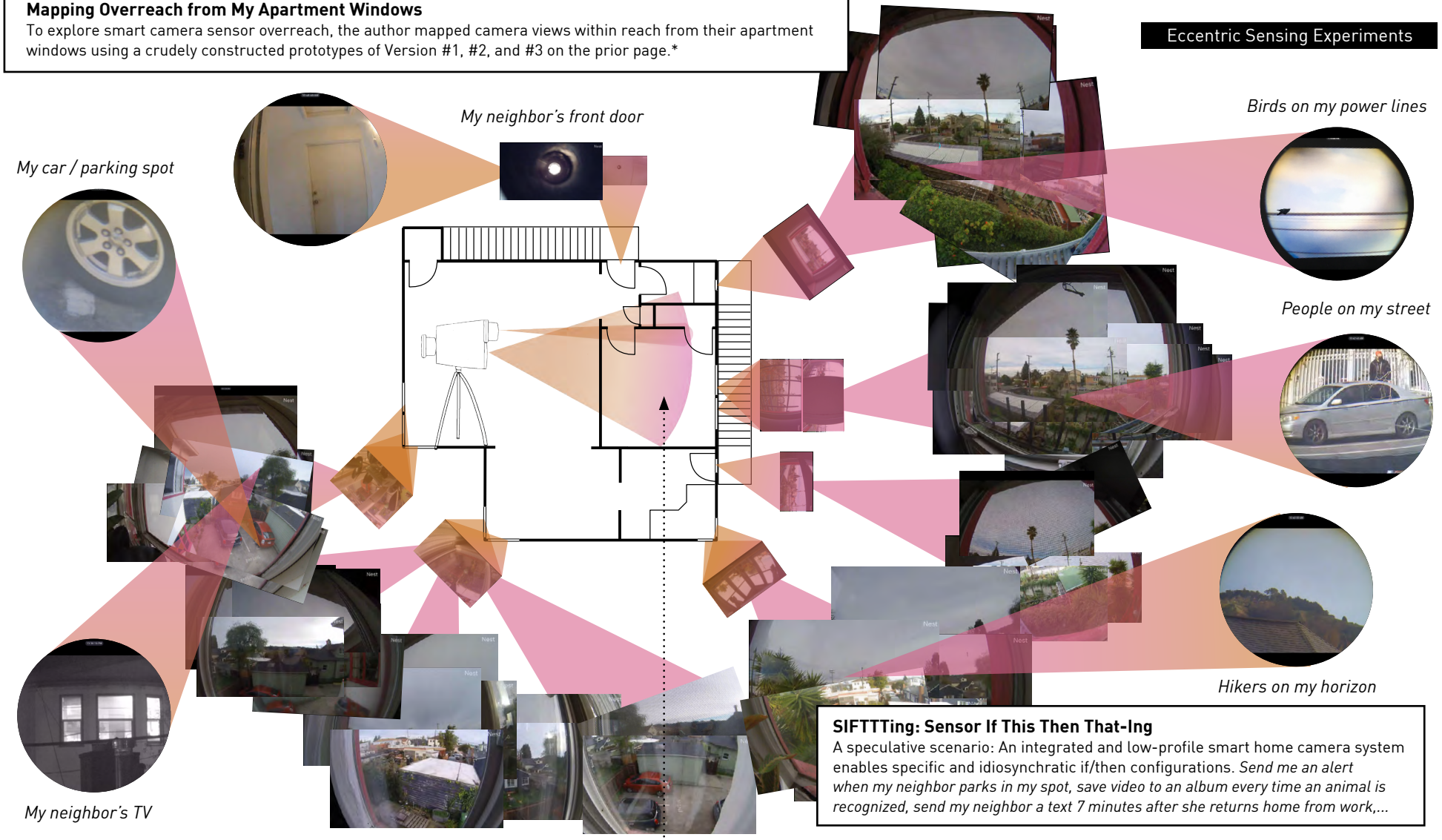


Subject *YOU* *Context*

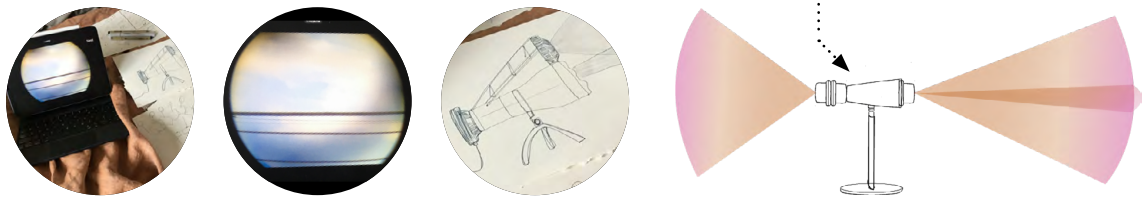
Version 3 : Version 2 + Rear-Facing Lens. Adding a third camera pointed in reverse directs focus back on the viewing subject. This view invites self-reflection and brings the power and accountability of the person directing the camera into the frame.

Mapping Overreach from My Apartment Windows
To explore smart camera sensor overreach, the author mapped camera views within reach from their apartment windows using a crudely constructed prototypes of Version #1, #2, and #3 on the prior page.*

Eccentric Sensing Experiments



SIFTTTing: Sensor If This Then That-Ing
A speculative scenario: An integrated and low-profile smart home camera system enables specific and idiosynchratic if/then configurations. *Send me an alert when my neighbor parks in my spot, save video to an album every time an animal is recognized, send my neighbor a text 7 minutes after she returns home from work,...*



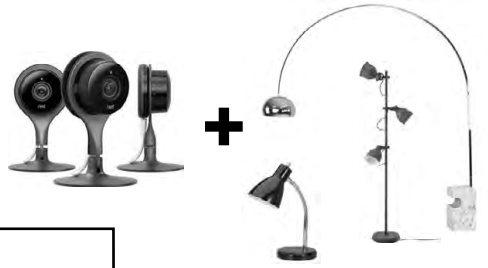
My design process
Eccentric camera views occassionally served as a backdrop for exploratory sketching. For example, overreach device variations were developed while waiting for birds to land on the power lines.

* These experiments were conducted to demonstrate social and experiential capabilities of current smart home camera technology, and to expose potential data privacy, security, and ethical concerns. Care was taken to not collect personally identifiable information, and experiments were conducted in accordance with local laws and guidance provide by camera manufacturers.

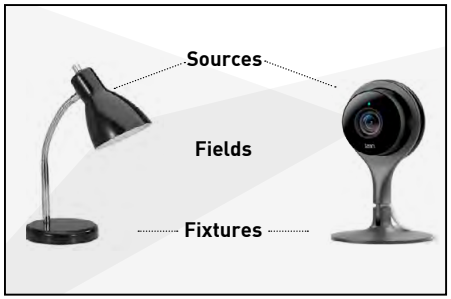
Layered Sensing Devices: Smart Cams + Light Fixtures

Eccentric Sensing Device Pattern

One smart camera is no longer enough. Smart cameras are now marketed in outdoor and indoor varieties, and sold in packs of 2, 3, 4, and 5 cameras. The list of manufacturers' suggested locations is ever-expanding: the nursery, the entryway, the shed, the basement. *Combining smart cameras with light fixtures illuminate how smart cameras create* **layered sensor fields** *within intimate, everyday environments.*

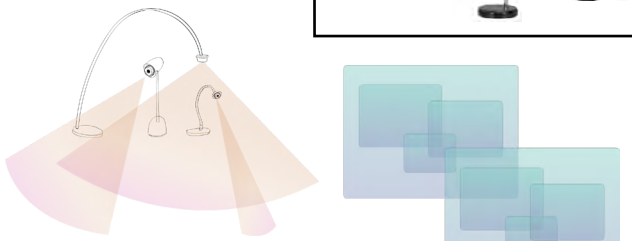


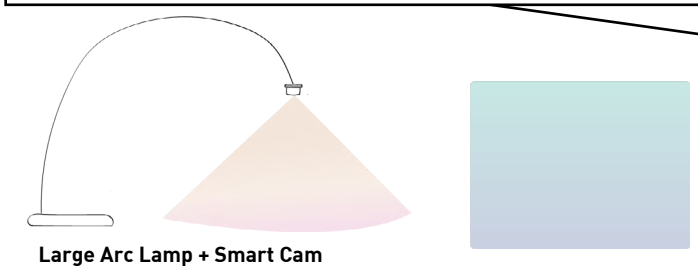
Analogous Designs: Lamps and Cameras
Smart cameras and electric lights exhibit a number of similarities. Both involve light. Both require fixtures for physical positioning. And both involve a spatial field: a field of view with a camera, and a field of illuminance with lamps.



Layers in Lighting Design and Cinematography
Lighting designers work with 3 main layers. *Ambient lighting,* or general-purpose lighting, provides overall lighting for a room. *Accent lighting,* or highlight lighting, creates focal points and draws attention to features or objects. *Task lighting* is used when doing specific activities like reading or cooking. These layers loosely parallel 3 key layered compositional shots in cinematography: *background, middleground*, and *foreground*. By replacing the light sources of common light fixtures with smart cameras, we imagine a future with 3 primary layers of smart camera illumination.

Camera Sensor Illumination Layers
Positioning cameras like lamps leads to reconceptualizing the camera field of view as a camera illumination layer. This shifts focus away from an engaged, viewing human subject toward an active physical space that can be watched, but also tracked, monitored, and analyzed computationally.





Large Arc Lamp + Smart Cam

Wide-Area Layers
Wide-area layers provide overall sensor illumination using a wide-angle lens. Distributed camera networks and computational photographic techniques can also be used to achieve wide-area coverage. The wide-area layer is analogous to the ambient lighting layer.

Medium Accent Lamp + Smart Cam

Precision-Zone Layers
Precise-zone layers provide illumination focused on specific spatial zones. The precise-zone layer is analogous to the accent lighting layer.

Small Desk Lamp + Smart Cam

Specific-Task Layers
Specific-task layers provide targeted illumination to support specific analysis, interaction, or activities. The specific-task layer is analogous to the task lighting layer. Specific task layers can be deactivated when a task is finished.

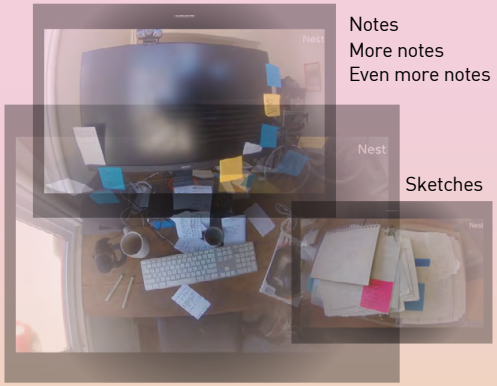
Eccentric Sensing Experiments

Lamp Cam Product Redirects
We constructed operational lamp cam devices and lived with them intermittently for time periods of up to 2 week periods. Our self-use studies involved committing to configuring the devices in different areas of our homes including configurations that felt uncomfortable or unnecessary.

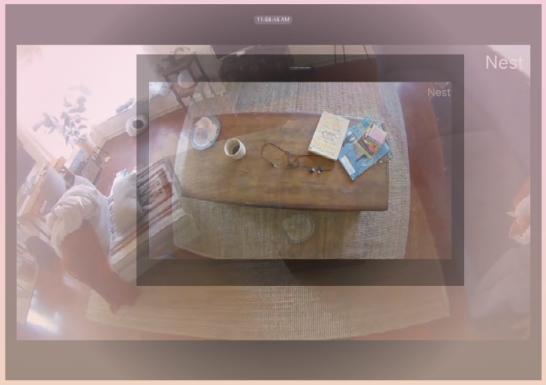
Self-Use: An Intimate, Layered Inward Gaze. The cameras forced us to take an honest look at our lives, homes, and things. Often we felt the urge to tidy up an unkept room or compose a more flattering shot. Partially blurred, these images represent a compromise between an honest, intimate look at the authors' home lives, and an impersonal, abstracted view.

Digital Analytics Layers. Smart cameras are more than cameras. Layered atop the image-data lie *digital analytics layers* of recognition, detection, and tracking. While living with the lamp cams we received many alerts when cameras thought they recognized motion, a person, or a loud activity. Alerts prompted us to then scroll through time-lapse videos revealing the mundane activities of family, pets, and roommates.

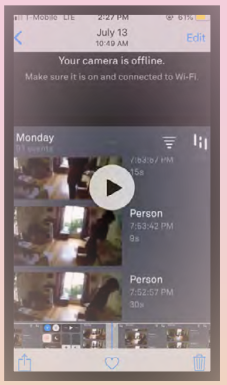
Casual Spying, Aesthetic Snapshots, and Self-Regulation. These digital analytics layers of camera illumination created opportunities to spy on family, strangers, and ourselves inadvertently and out of curiosity. Another emergent use/effect was self-regulation. At times we regulated our behavior, altering our actions to align with how we thought we ideally should act, e.g., making our beds, tidying our homes, covering our bodies, correcting our postures, concealing vices, etc.



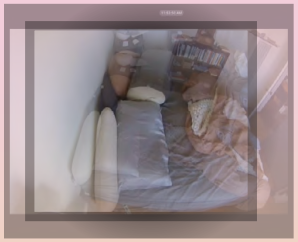
Work From Home Office



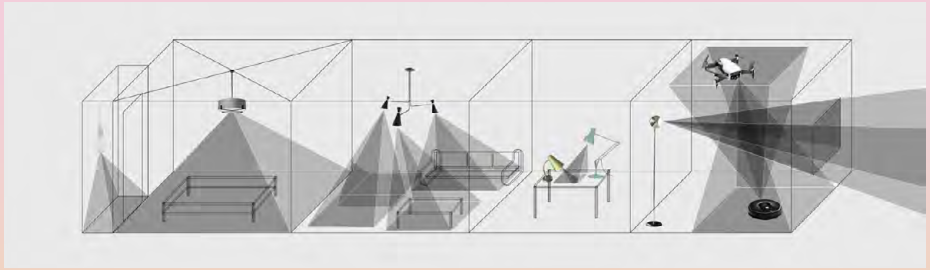
Living Room



Alerts



Bedroom

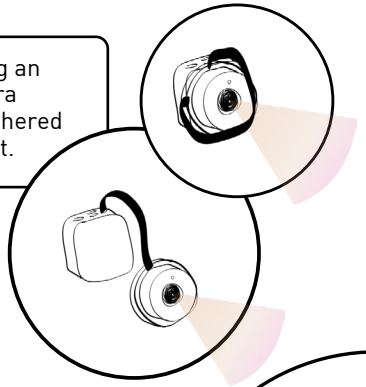


Eccentric Sensing Device Pattern

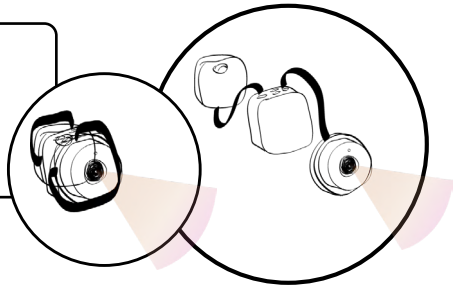
Floating Sensor Devices: Smart Cam + Battery + Location Trackers

Adding an external battery untethers the smart home security camera, *allowing a small, powerful sensing device to* ***float around***. Adding location and activity sensing capabilities helps keep track and maintain control of "off-leash" sensing devices.

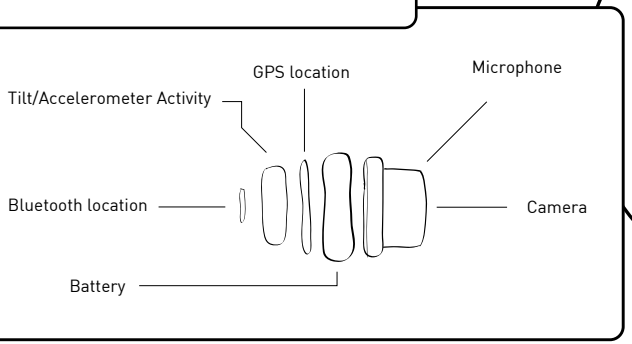
Version 1: Battery + Smart Cam. Affixing an external battery to a smart home camera enables the device to float around, untethered from a wall, floor, or ceiling power outlet.

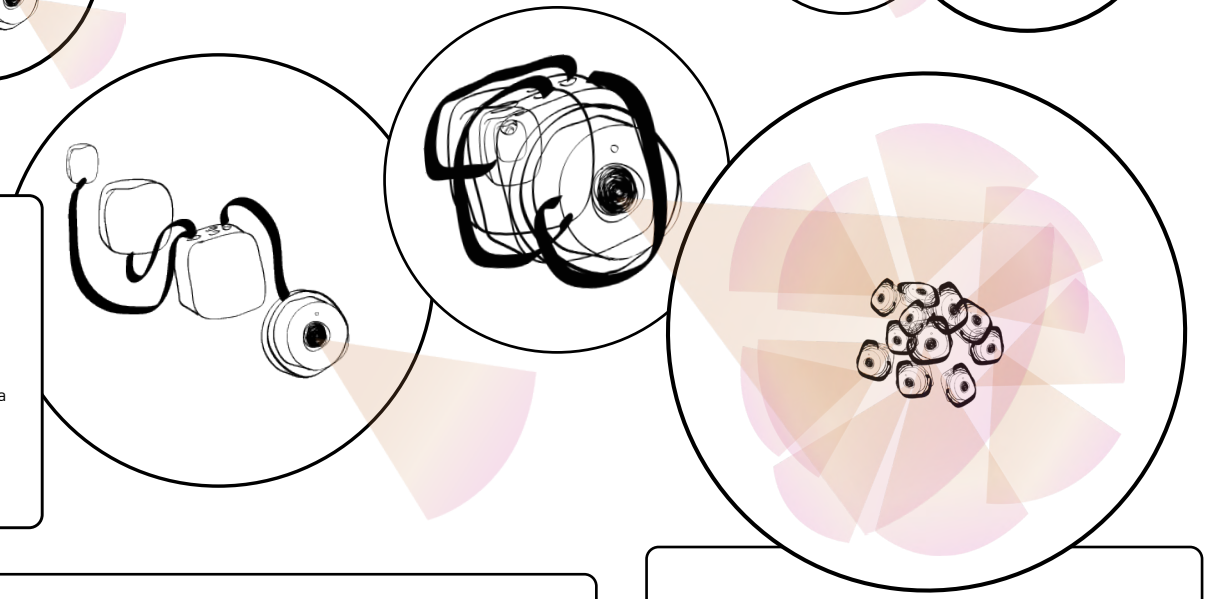


Version 2: Version 1 + Location Tracker. To help keep track of floating sensor systems, a bluetooth location tracker is added. The device can now be tracked on a map display, and paged using an auditory locator.



Version 3: Version 2 + Activity Trackers. An activity tracker is added for more granular activity data using an accelerometer and tilt sensor.



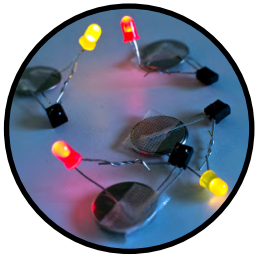


A composite external display unit invites an eccentric viewing relationship to a handful of small, mobile sensor units strewn about.

Sensors strewn around, scattered about... Like dogs on a leash, power cords and WiFi connections tether smart cameras to power outlets and routers. Smaller, cheaper, and more mobile sensing systems open up new possibilites for precise, distributed configurations. They also enable the devices to be tossed around in a casual, haphazard, or reckless manner.

Readymade Smart Cam Throwies
Inspired by Graffiti Research Lab's LED throwies [20], we constructed smart camera throwies using inexpensive Yi and Wyze smart home cameras, Tile and Samsung smart trackers, external smartphone batteries, and common attachment mechanisms including magnets, velcro, double-side tape.

LED throwies

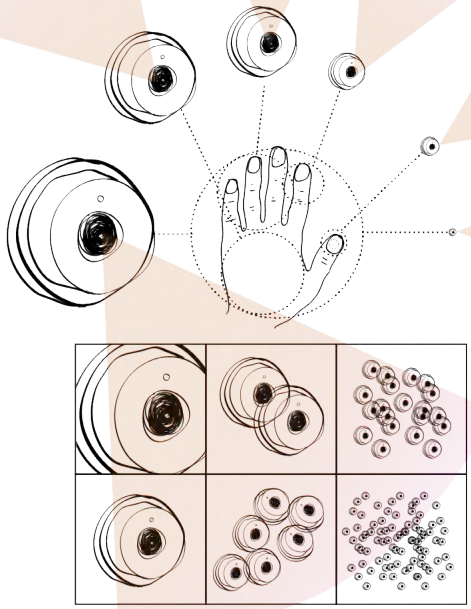


Smart Cam Throwies

In a houseplant
Between the couch cushions
In a drawer
In the medicine cabinet
Under a pile of clothes
Among some papers

On a tree
In the mailbox
Under a sewer grate
On a bike rack
On a street sign
On a flyer

Cost Comparison
Currently a single smart cam throwie can be assembled for a cost of approximately $40 USD. For comparison, $1 USD gets you approximately 1 LED throwie. As the cost of smart cameras declines, we might expect to continue to find camera sensors all over the place, even when we don't really want or need them—much like how we find unnecessary LEDs and displays on electronic devices.



Sensor Size Matters. Seemingly small details and attributes can make big effects. Size is one such aspect. A large, heavy sensor will tend to get stuck in a specific location. A tiny, lightweight sensor will tend to move about, become concealed, and get lost. Curren smart home cameras are about the size of the palm of your hand. What happens as smart camera systems get incrementally smaller? **Finger-sized.** Can be easily "palmed," i.e., tightly held and concealed in the palm of your hand. **Digit-sized.** Can be placed in a pocket without bulging out. **Thumbnail-sized.** Difficult to find if your kid or cat knocks it off the table. **Pebble-sized.** Can be wedged into a small hole in the wall or sidewalk. **Pinhole-sized.** Can be pasted onto any surface, or implanted into your forehead.

Dot, Hole, or Sensor?
As sensors get smaller, cheaper, and more mobile, they begin to appear where they might not actually exist...

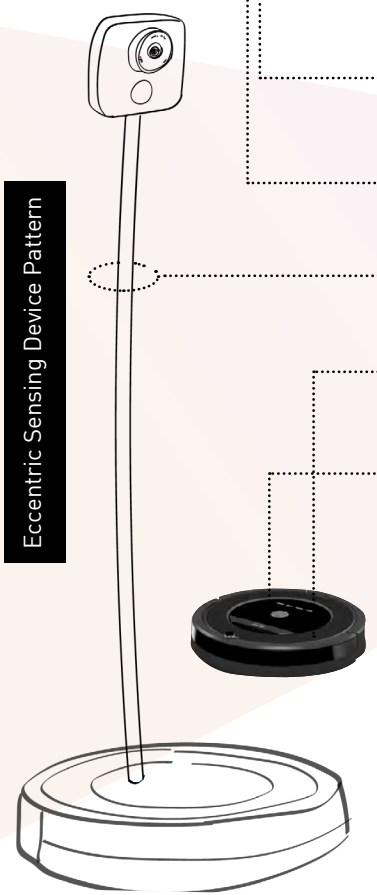
Unpredictable Sensing Devices: Smart Cameras + Roombas

Have you heard the joke about the smart camera riding a Roomba? The punchline is some sort of allegory about the **unpredictability of autonomous sensing devices.**

Roomba + Clips
The eccentric Roomba + Clips device mechanically couples two autonomous smart products: the Google Clips camera and iRobot Roomba vacuum. The resultant device compounds the unpredictable autonomy of each individual product.

Google Clips Cam
Clips is a "hands-free wireless camera" that uses artificial intelligence to automatically capture photos it thinks you might enjoy.

Eccentric Sensing Device Pattern



Computational Brain #1

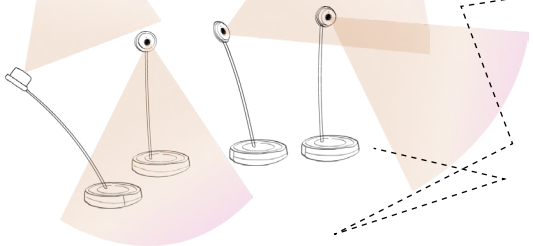
Digital Eye

Mechanical Flex-Neck

Computational Brain #2

Robotic Body

iRobot Roomba
Roomba is a robotic smart vacuum cleaner that uses automation and artificial intelligence to clean areas it think you want cleaned.



Social-spatial boundary

Sensor Attenuation Devices: Smart Cameras + Curtains

Better controls and safeguards are needed for layered, overreaching, floating, and unpredictable sensing devices. *A curtain provides* **shades of sensing attenuation** *in between fully ON and completely OFF.*

Eccentric Sensing Device Pattern

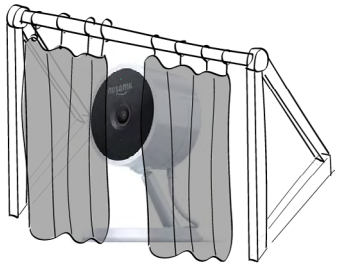
The Current State of Smart Camera Controls
As with many IoT devices, the smart home camera interface supports and encourages an "always-on" interaction paradigm. For example, the Amazon Cloud Cam contains no physical On/Off button. The virtual buttons to disable the camera and microphone are buried several screens deep in the apps information architecture. Indicator lights are also unreliable. A light may be lit but the security camera is actually Off, and vice versa.

Smart cameras, like most digital sensing systems, are characterized by 3 main sensor control states: On, Off, and Very Off. Window curtains suggest a fourth option: variably attenuated somewhere between complete deactivation and partial impairment.

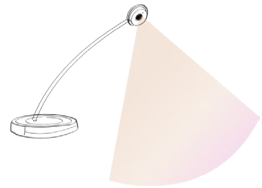
ON **OFF**

Very OFF
A webcam cover or unplugging the power source are among the most reliable ways to ensure a smart camera is deactivated and no longer sensing.

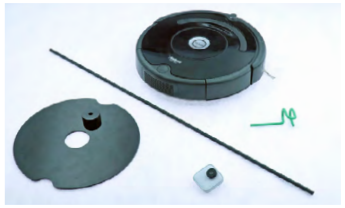
Attenuating Curtains
Adding curtains to a smart cam allows light-data passing from the environment to the image-sensor to be regulated more flexibly, saliently, and reliably than using the manufacturer's virtual button and unreliable indicator light.



Transgressing Boundaries
Unpredictable sensing exacerbates potentials for sensors to overreach and cross *socio-spatial boundaries* such as property lines, window panes, and personal space.

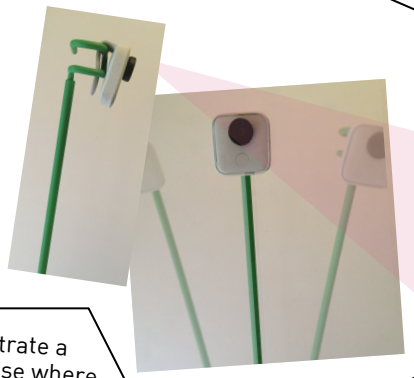


Roomba+Clips Accessory Kit. We built an accessory kit that combines a Roomba robotic vacuum and a Clips machined-vision powered camera. Numerous iterations were conducted to determine a suitable coupling. A one-meter long ABS plastic neck achieved a satisfying swaying effect each time the Roomba strikes a wall or objects and turns to traverse elsewhere. At roughly the height of a small child, the device appears to stand upright, vaguely resembling an athropod.



"Intelligent" Unpredictability as Design Quality. Most smart products emphasize precision and predictability. The Roomba+Clips construction instead highlights unpredictable design qualities such as unstable views and unexpected movements.

Living with Unpredictably Autonomous Things. Unpredictable products offer potentials to surprise, delight, and entertain us. But they can also go off the rails in ways that are unpleasant, invasive, or even harmful.



Losing Control
Roomba and Clips individually demonstrate a future where smart devices go and sense where they please. Our eccentric Roomba+Clips device amplifies both the playful positive opportunities and the unwelcome negative impacts of devices less fully within our reach and control.

Manual Interaction Overrides
Bumbling, autonomous devices highlight the need for manual interaction overrides. The Roomba is designed with an intuitive manual human override: lift up the device from the ground and it automatically deactivates. Clips is similarly designed with manual overrides: twist the lens to turn on/off and press the button to manually take a photo. One type of manual interaction override involves using a physical overlay, such as a curtain... ●

Smart Camera + Curtains Accessory Kit. We created an accessary kit for adding curtains to existing consumer smart home cameras. The version pictured above involves a dual rod design supporting two curtain types. The solid, decoratively dotted curtain blocks nearly all light from passing through. The loosely knit curtain blocks faces and other details while allowing the basic contours of shapes and motion to be detected.

Blocking Some | Blocking Faces | Blocking Most | Blocking Everything *

Smart Camera + Curtains Accessory Kit. The curtain kits were informed by our experiments using textiles to attenuate sensor capabilities, including analytics functions. Different weaves were used to modulate or even switch on and off features such as person alerts and facial recognition. In addition to attenuating sensing, camera curtains can also regulate the social atmosphere by setting guests at ease, or inviting dwellers to reliably turn their sensing devices off.

What if you don't own or operate the device? Smart cameras aren't always within reach or under our control. Many people place smart cameras inside their window sills pointed outward at neighbors, customers, and passersby. A second version of our kit enables you to intervene delicately, if passive aggressively, by blocking a neighbor's smart camera.

Emerging social etiqutte. While our interventionist curtain kit will seldom provide the correct social solution to a neighborly tension, the design does highlight the issue of emerging social etiqutte around layered, overreaching, and floating sensing devices. Curtain-inspired overlay controls might help facilitate suitable social protocols by creating visible and tangible points of discussion and interaction.

* Small amounts of ambient light can still be detected revealing, for example, nearby motion.

Using Notes and Eccentric Sensing Devices to Address Privacy, Security, and Data Ethics Challenges

Across the prior pages we've presented an array of conceptual design notes. Each note links to an eccentric sensing device. And all notes cluster around a theme representing a mixture of design oppportunties, limitations, and concerns. By design, we've laid out these notes in irregular clusters rather than linear lists or orthogonal grids. On this page we draw out two, tidier categories with which to apply and extend our conceptual design notes to addess timely challenges with privacy, security, and data ethics. On the left, we present a sample of concepts oriented toward helping designers craft interfaces and experiences. On the right, we broaden beyond interface design and offer a sample of concepts for understanding issues of surveillance, privacy, and power. These concepts demonstrate uses of design as a tool to develop ideas that extend beyond the traditional disciplinary boundaries of design and HCI.

Sensor Field Metaphors

Engineers distinguish 3 main categories of sensors: passive narrow beam sensors (e.g., cameras), passive omnidirectional (e.g., mics), and active (e.g., GPS). In this research we've extended this engineering vocabulary through the metaphor of a sensor field: a physical, geographical, and embodied space in which a sensor senses. We've found this metaphor useful for understanding design opportunities, limitations, and concerns connected to smart sensing devices. The sensor field metaphor—as depicted throughout this pictorial—paints a picture of a physical world overlaid with an invisible sensor interface. The sensor field metaphor further illuminates how sensors activate space, and how these perceptually powerful spaces intersect with heightened privacy and security concerns.

Narrow-beam sensor field
Example: A camera

Omnidirectional sensor field
Example: A microphone

Active sensor field
Example: GPS

Articulating Sensor Design Qualities

Designers often articulate qualities that encapsulate possible or desireable experiential outcomes that can be crafted with various design materials. Within interaction design, for example, practitioners talk about crafting fluid, responsive, and neumorphic interfaces. HCI researchers explore ways of crafting supple [23], slow [27], and ludic [18] interactions. Following prior design research [23,24,29], we argue that further work is needed to articulate the unique experiential and material qualities of specific sensors and systems. For example, some sensor fields such as cameras, microphones, and radar tend to spread across space, bleed through walls, and leak across other ***socio-spatial boundaries*** (page 9). Others, such as GPS, accelerometers, and heart rate sensors are more spatially localized to a sensor hardware device.

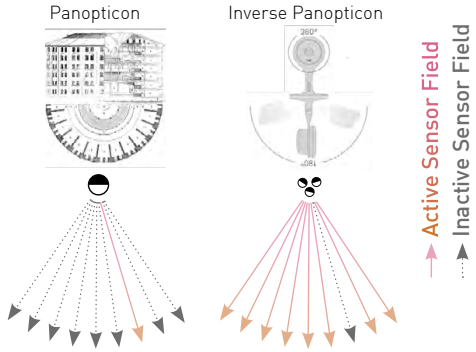
This pictorial has contributed to a body of research on design qualities [e.g.,1,2,10,29,38,44] by using eccentric sensing devices to isolate and amplify qualities demonstrated by current smart home camera products, which involve camera sensors as well as microphones and advanced data-analytics capabilities. Smart cameras can ***overreach***, extending through windows and across property lines. Smart camers can ***float*** around, creating opportunities to get lost and make trouble. Smart cameras can be ***layered*** to form an expansive activated space capable of detecting, recognizing, and tracking activity. Smart cameras can be ***unpredictable***, as when breaching a social boundary or automatically triggering an alert or action. Finally, the layered, unpredictable, floating, and overreaching sensor fields of smart cameras can be ***attenuated*** ranging from complete deactivation to partial impairment. These qualities can be used and extended in many directions. For example, designers might amplify unpredictability to create more playful and serrendipitous experiences. Conversely, designers might create more granular and reliable ***interaction overrides*** and safeguards (page 10) that attenuate the perceptually powerful fields of sensing systems. Beyond any specific quality or design direction, though, this pictorial has demonstrated a creative approach to investigating sensor qualities using eccentric devices.

The Sensorification of Daily Life

When electric lighting was introduced in the 1900s as the first large-scale application of electricity many experts and members of the public expressed fears and anxieties. But electricity eventually evolved into a normal, ubiquitous, and indispensible aspect of daily life. A similar trend with digital sensors may currently be underway. With smart cameras, for example, systems are becoming cheaper, the range of image/video analytics applications is expanding rapidly, and smart cameras are becoming more normal and accepted—as evidenced by indoor smart cameras, wearable cameras, and cameras integrated into doorbells, vehicles, and more. Expanding well beyond rational and utilitarian use cases, our eccentric sensing devices imagine a future where sensing systems advance to the point where—like electricity and computation—they are commonly used for *aesthetic, idiosynchratic, silly, and superflouous applications*.

The Inverse Panopticon

Bentham's famous panopticon system employs a single human guard to monitor many prisoners. The panopticon surveillance model explains how the mere possibility of surveillance exerts control over our behaviors. However, as sensors become cheaper, more numerous, and more mobile—and more layered, overreaching, and untethered—the panopticon begins to invert. Nowadays, it's safer to assume that there actually *is* a camera or microphone around. And if so, that sensor is much more likely to be sensing than not. Complementing other updated models of surveillance [e.g., 6,45,46] , the inverse panopticon suggests two competing design philosophies. The *reasonably paranoid threat model*, where users should assume absolutely everything is sensing (see pages 9 and 10). And a *big boring data model*, where users can relax knowing that most intimate data ultimately reveals very little (see pages 4 and 6).



Sensing Asymmetries

Sensor fields activate space. This spatial activation can transform a physical space into a digital interface—a site for interaction wherein human and environmental actions trigger machine reactions and vice versa. Yet this activated space/interface carries a number of asymmetric relations uncovered by our eccentric sensing experiments. *Sensor perception asymmetries:* A smart camera field of vision has great perceptual powers, yet the location of its sensing field cannot be directly felt, heard, or seen by humans. In other words, sensor fields lacks inherent feedback. *Sensor control asymmetries:* You can point a camera into your neighbor's yard or place a microphone near your roomate's bedroom, and they may have little direct awareness or recourse. *Power asymmetries:* A landlord, parent, or employer may exploit these perceptual and control asymmetries, and wield a sensing device with greater social and legal power than tenants, kids, and domestic workers. In these ways sensor field interfaces are very different from conventional computer interfaces.

Reflecting on Method: Notes on Notes, and Eccentricity

In conclusion, we reflect upon our creative research practice. We elaborate on our approach to generating eccentric sensing devices. And we discuss our creation and presentation of design research via conceptual design notes. Both of these aspects of our approach may be usefully applied and extended to others issues and domains beyond digital sensing and privacy, security, and data ethics. More generally, we draw out methodological ideas that others may use to divergently explore a design space, and which demonstrate the value of *intimately articulating the creative process and intermediate outcomes* **as a final product.**

Sensitizing Concept for Crafting Eccentric Devices

We see signs of an eccentric device approach across many areas of HCI and design research, including Gaver et al's ludic prototypes [18], Wakkary et al's counterfactual things [39], Pierce et al's counterfunctional devices [33], Yurman's provocative nursery designs [47], and Berger et al's idiosyncratic ideation [4]. Here we briefly reflect upon how we create conceptually rich eccentric sensing devices so others can apply and adapt our emergent techniques. As with all creative activity, design inquiry can be messy [13,16]. Even in retrospect and with the benefit of distance, tracing a clean narrative line and connecting the disparate dots may prove difficult, or worse, misleading. Nonethless, articulating method and process in ways that others can reuse, adatop, and reflect upon is a core area in which design research contributes new knowledge. Articulating method or process also helps render legible other knowledge contributions. Reflecting upon the various twists and turns of this meandering research project, we draw out several ideas that emergently guided our process. These *sensitizing concepts* are less structured and linear than methods, less formal and dogmatic than principles, and more fluid, fragmentary, and open-ended than design patterns or strategies.

Eccentric Devices. Eccentric devices represents the core approach underlying the conceptual designs and notes we've presented. The approach is oddly simple: create unusual devices guided loosely by the aims of exploring design opportunities, limitations, and concerns. In this project we focus on issues connected to digital sensing systems. While there is no single right or wrong way to go about creating eccentric sensing devices, one approach we favor is a two-step process. Step 1: use intuition or randomness to create an odd device. Step 2: Think about the device. If the device proves useful as a tool for understanding design opportunities, limitations, and concerns, iterate on the design and continue to reflect. If not, go back to Step 1.

Product Redirection. Rather than making sensing devices from whole cloth, we use off-the shelf consumer products and everyday things as design materials. *Amplifying*, *restraining*, and *deviating* are three main redirective strategies we employ time and again. To amplify, identify a feature and multiple it times 10, or 1,000. To restrain, limit or remove a capability. To deviate, try the opposite, or something altogether unexpected, unlikely, or perhaps absurd.

Anchored Speculation. Production redirection naturally encourages a second approach we call anchored speculation. By literally using existing products as foundations or building blocks in design, product redirection grounds unconventional design ideas in existing technologies. Our eccentric sensing devices tend to make only incremental technological changes, while taking more audacious social leaps. The devices are designed to encourage imaginative flights anchored in familiar and realistic everyday things and experiences.

Forming Conceptual Design Notes

Our approach to creating conceptual design notes represents a soft break with a prevailing research through design approach modeled after product development and R&D (research and development) processes wherein the team moves from early proposals to operational prototypes. These prototypes are then often deployed and assessed empirically. Let's call this the *make/deploy/assess model*. This model may surely yield insightful and inspiring outcomes. But it is far from the only way of doing design research.

Diverging from the make/deploy/assess model, we instead present an ecclectic and integrated array of written and material things under the framework of conceptual design notes. In terms of our process, the activities of reflecting, writing, drawing, making, and using are so tightly interwoven that the distinctions begin to blur. Historically, our process for creating this pictorial went roughly like this: design some eccentric things, think about them, make some ideas, write them out, design more things to represent and/or explore these ideas, repeat until the pictorial is ready and the submission deadline is at hand.

Our approach of making conceptual design notes connects to Bowers and Gaver's concept of annotated portfolios [5,17]. However our approach subtly diverges in two important regards. First, with regards to process we merge the activities of (an)notating and designing. Instead of treating annotations as a secondary layer of verbal knowledge added atop an already designed ir nade thing, we approach the creation of conceptual notes and conceptual things as an intertwined process. Second, with regards to outcomes we grasp designs less as discrete material things and more in terms of what feminist theorists describe as figurations that merge the material and the semiotic, or representational [9,21]. A concrete effect of this philosophy is that we make a variety of things: drawings, diagrams, physical sketches, material experiments, and robust prototypes.There are, of course, real and consequential differences between a drawing of a thing and an actual thing held in one's hand. But we should not overlook the ways in which we also hold drawings in our hands, whether on paper or screen. Informed by this perspective shift, we invite reading our work along a flatter ontological hierarchy, one that softens distinctions among common design categories such as sketch, prototype, proposal, product, specification, scenario, documentation, and so on.

We find that conceptual design notes offers a fruitful complementary model for doing design research that can amplify the powers of design to articulate a richly nuanced and layered space of possibilities. To the extent that design research is valued because of its inspirational and generative potentials, conceptual design notes invite readers to engage with the work in a manner closer to the experiential processes of doing exploratory, speculative, and conceptual design inquiry—complete with twists, turns, and the occassional dead end.

Conclusion: Making and Using Conceptual Design Notes

We began with engineering concepts of ubiquitous, distributed, miniaturized, and autonomous networked sensing devices, and with marketing ideas of smart, connected, IoT devices. We ended with a set of complementary concepts for grasping ubiquitous smart devices as overreaching, layered, floating, unpredictable, and attenuated. This list is, of course, far from exhaustive. With the methodological tools of eccentric sensing devices and conceptual design notes, researchers may continue to creatively explore the opportunities, limitations, and concerns connected to smart sensing systems and interactive technologies. More generally, eccentric devices and conceptual design notes offer a route to divergently exploring a design space, and exemplify the value of intimate and nuanced depictions of creative processes—details too often ommited from final publications and finished products.

Acknowledgments

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References

1. Arvola, Mattias. "Interaction Design Qualities: Theory and Practice." In Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries, 595–598. ACM, 2010
2. Bardzell, Shaowen, Daniela K. Rosner, and Jeffrey Bardzell. "Crafting Quality in Design: Integrity, Creativity, and Public Sensibility." In Proceedings of the Designing Interactive Systems Conference, 11–20. ACM, 2012.
3. Biddle, Sam. "Troubling Study Says Artificial Intelligence Can Predict Who Will Be Criminals Based on Facial Features." The Intercept (blog), November 18, 2016. https://theintercept.com/2016/11/18/troubling-study-says-artificial-intelligence-can-predict-who-will-be-criminals-based-on-facial-features/
4. Berger, Arne, William Odom, Michael Storz, Andreas Bischof, Albrecht Kurze, and Eva Hornecker. "The Inflatable Cat: Idiosyncratic Ideation of Smart Objects for the Home." In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, 401:1-401:12. CHI '19. New York, NY, USA: ACM, 2019. https://doi.org/10.1145/3290605.3300631.
5. Bowers, John. "The Logic of Annotated Portfolios: Communicating the Value of 'Research Through Design.'" In Proceedings of the Designing Interactive Systems Conference, 68–77. DIS '12. New York, NY, USA: ACM, 2012. https://doi.org/10.1145/2317956.2317968.
6. Browne, Simone. Dark Matters: On the Surveillance of Blackness. Duke University Press, 2015. https://books.google.com/books?hl=en&lr=&id=snmJCgAAQBAJ&oi=fnd&pg=PT5&dq=browne+dark+matter+surveillance&ots=t8FYD07B5a&sig=PFobXK-SGwYMZYlETef6sL9Q06M.
7. Buchenau, Marion, and Jane Fulton Suri. "Experience Prototyping." In Proceedings of the 3rd Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques, 424–33. DIS '00. New York, NY, USA: ACM, 2000. https://doi.org/10.1145/347642.347802.
8. Busso, Carlos, Zhigang Deng, Serdar Yildirim, Murtaza Bulut, Chul Min Lee, Abe Kazemzadeh, Sungbok Lee, Ulrich Neumann, and Shrikanth Narayanan. "Analysis of Emotion Recognition Using Facial Expressions, Speech and Multimodal Information." In Proceedings of the 6th International Conference on Multimodal Interfaces, 205–211. ICMI '04. New York, NY, USA: ACM, 2004. https://doi.org/10.1145/1027933.1027968
9. Castañeda, Claudia. Figurations: Child, Bodies, Worlds. Duke University Press, 2002.
10. Cila, Nazli, Iskander Smit, Elisa Giaccardi, and Ben Kröse. "Products As Agents: Metaphors for Designing the Products of the IoT Age." In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, 448–459. CHI '17. New York, NY, USA: ACM, 2017. https://doi.org/10.1145/3025453.3025797.
11. Clifford, Stephanie, and Quentin Hardy. "Attention, Shoppers: Store Is Tracking Your Cell - The New York Times." Accessed September 11, 2019. https://www.nytimes.com/2013/07/15/business/attention-shopper-stores-are-tracking-your-cell.html
12. Desjardins, Audrey, and Aubree Ball. "Revealing Tensions in Autobiographical Design in HCI." In Proceedings of the 2018 on Designing Interactive Systems Conference 2018, 753–64. ACM, 2018.
13. Desjardins, Audrey, and Cayla Key. "Parallels, Tangents, and Loops: Reflections on the 'Through' Part of RtD." In Proceedings of the 2020 ACM Designing Interactive Systems Conference, 2133–47. DIS '20. New York, NY, USA: Association for Computing Machinery, 2020. https://doi.org/10.1145/3357236.3395586.
14. Devendorf, Laura, and Kimiko Ryokai. "Being the Machine: Exploring New Modes of Making." In Proceedings of the 2014 Companion Publication on Designing Interactive Systems, 33–36. DIS Companion '14. New York, NY, USA: ACM, 2014. https://doi.org/10.1145/2598784.2602775.
15. Gaver, Bill, Tony Dunne, and Elena Pacenti. "Design: Cultural Probes." Interactions 6, no. 1 (1999): 21–29.
16. Gaver, William. "What Should We Expect from Research Through Design?" In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 937–46. CHI '12. New York, NY, USA: ACM, 2012. https://doi.org/10.1145/2207676.2208538.
17. Gaver, Bill, and John Bowers. "Annotated Portfolios." Interactions 19, no. 4 (July 2012): 40–49. https://doi.org/10.1145/2212877.2212889.
18. Gaver, William W., John Bowers, Kirsten Boehner, Andy Boucher, David W.T. Cameron, Mark Hauenstein, Nadine Jarvis, and Sarah Pennington. "Indoor Weather Stations: Investigating a Ludic Approach to Environmental HCI Through Batch Prototyping." In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 3451–60. CHI '13. New York, NY, USA: ACM, 2013. https://doi.org/10.1145/2470654.2466474.
19. Giaccardi, Elisa, Nazli Cila, Chris Speed, and Melissa Caldwell. "Thing Ethnography: Doing Design Research with Non-Humans." In Proceedings of the 2016 ACM Conference on Designing Interactive Systems, 377–87. DIS '16. New York, NY, USA: ACM, 2016. https://doi.org/10.1145/2901790.2901905.
20. "Graffiti Research Lab » LED Throwies." Accessed February 21, 2021. http://www.graffitiresearchlab.com/blog/projects/led-throwies/.
21. Haraway, Donna. Simians, Cyborgs, and Women: The Reinvention of Nature. Routledge, 2013.
22. Howell, Noura, Greg Niemeyer, and Kimiko Ryokai. "Life-Affirming Biosensing in Public: Sounding Heartbeats on a Red Bench." In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, 1–16, 2019.

23. Isbister, Katherine, and Kristina Höök. "On Being Supple: In Search of Rigor Without Rigidity in Meeting New Design and Evaluation Challenges for HCI Practitioners." In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2233–42. CHI '09. New York, NY, USA: ACM, 2009. https://doi.org/10.1145/1518701.1519042.
24. Koskinen, Ilpo, John Zimmerman, Thomas Binder, Johan Redstrom, and Stephan Wensveen. Design Research through Practice: From the Lab, Field, and Showroom. Elsevier, 2011.
25. Löwgren, Jonas and Erik Stolterman. Thoughtful Interaction Design: A Design Perspective on Information Technology. MIT Press, 2004
26. Niemann, Christopher, "I'm House-Sitting for Friends—Can I Turn Their Nest Cam Off?" Wire Magazine. October, 26, 2016.
27. Odom, William, Mark Selby, Abigail Sellen, David Kirk, Richard Banks, and Tim Regan. "Photobox: On the Design of a Slow Technology." In Proceedings of the Designing Interactive Systems Conference, 665–68. DIS '12. New York, NY, USA: ACM, 2012. https://doi.org/10.1145/2317956.2318055.
28. Park, Seung-min, Daeyoun D. Won, Brian J. Lee, Diego Escobedo, Andre Esteva, Amin Aalipour, T. Jessie Ge, Jung Ha Kim, Susie Suh, and Elliot H. Choi. "A Mountable Toilet System for Personalized Health Monitoring via the Analysis of Excreta." Nature Biomedical Engineering, 2020, 1–12.
29. Pierce, James, Richmond Y. Wong, and Nick Merrill. "Sensor Illumination: Exploring Design Qualities and Ethical Implications of Smart Cameras and Image/Video Analytics." In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, 1–19, 2020.
30. Pierce, James. "Smart Home Security Cameras and Shifting Lines of Creepiness: A Design-Led Inquiry." In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, 1–14, 2019.
31. Pierce, James. "Lamps, Curtains, Robots: 3 Scenarios for the Future of the Smart Home." In Proceedings of the 2019 on Creativity and Cognition, 423–24, 2019.
32. Pierce, James. "Roomba+ Clips Cam: Exploring Unpredictable Autonomy in Everyday Smart Systems." In Companion Publication of the 2020 ACM on Designing Interactive Systems Conference, 317–20, 2020.
33. Pierce, James, and Eric Paulos. "Some Variations on a Counterfunctional Digital Camera." In Proceedings of the 2014 Conference on Designing Interactive Systems, 131–40. DIS '14. New York, NY, USA: ACM, 2014. https://doi.org/10.1145/2598510.2602968.
34. "Realeyes." Accessed September 11, 2019. https://www.realeyesit.com
35. Sengers, Phoebe, Kirsten Boehner, Shay David, and Joseph "Jofish" Kaye. "Reflective Design." In Proceedings of the 4th Decennial Conference on Critical Computing: Between Sense and Sensibility, 49–58. CC '05. New York, NY, USA: ACM, 2005. https://doi.org/10.1145/1094562.1094569.
36. Stappers, Pieter Jan, and Elisa Giaccardi. "Research through Design | The Encyclopedia of Human-Computer Interaction, 2nd Ed." Accessed September 18, 2019. https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/research-through-design.
37. Sundström, Petra, Alex Taylor, Katja Grufberg, Niklas Wirström, Jordi Solsona Belenguer, and Marcus Lundén. "Inspirational Bits: Towards a Shared Understanding of the Digital Material." In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 1561–70. CHI '11. New York, NY, USA: ACM, 2011. https://doi.org/10.1145/1978942.1979170.
38. Torres, Cesar, Jasper O'Leary, Molly Nicholas, and Eric Paulos. "Illumination Aesthetics: Light As a Creative Material Within Computational Design." In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, 6111–6122. CHI '17. New York, NY, USA: ACM, 2017.
39. Wakkary, Ron, Doenja Oogjes, Henry W. J. Lin, and Sabrina Hauser. "Philosophers Living with the Tilting Bowl." In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, 94:1-94:12. CHI '18. New York, NY, USA: ACM, 2018. https://doi.org/10.1145/3173574.3173668.
40. Wakkay, Ron, and Leah Maestri. "The Resourcefulness of Everyday Design." In Proceedings of the 6th ACM SIGCHI Conference on Creativity & Cognition, 163–72. C&C '07. New York, NY, USA: Association for Computing Machinery, 2007. https://doi.org/10.1145/1254960.1254984.
41. Blythe, Mark, Enrique Encinas, Jofish Kaye, Miriam Lueck Avery, Rob McCabe, and Kristina Andersen. "Imaginary Design Workbooks: Constructive Criticism and Practical Provocation." In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, 233:1-233:12. CHI '18. New York, NY, USA: ACM, 2018. https://doi.org/10.1145/3173574.3173807.
42. Aipperspach, Ryan, Ben Hooker, and Allison Woodruff. "The Heterogeneous Home." In Proceedings of the 10th International Conference on Ubiquitous Computing, 222–31. UbiComp '08. New York, NY, USA: ACM, 2008. https://doi.org/10.1145/1409635.1409666.
43. Gaver, William. "Making Spaces: How Design Workbooks Work." In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 1551–60. CHI '11. New York, NY, USA: ACM, 2011. https://doi.org/10.1145/1978942.1979169.
44. Lim, Youn-kyung, Sang-Su Lee, and Da-jung Kim. "Interactivity Attributes for Expression-Oriented Interaction Design." International Journal of Design 5, no. 3 (2011). http://128.199.168.50/index.php/IJDesign/article/view/718.
45. Hu, Tung-Hui. A Prehistory of the Cloud. MIT Press, 2015. https://books.google.com/books?hl=en&lr=&id=QQNmCgAAQBAJ&oi=fnd&pg=PR5&dq=hu+prehistory+of+the+cloud&ots=NDOdnPK-EJ&sig=-MD8wHIzPN25wuIrM5Ox_ivaRX0.
46. Zuboff, Shoshana. The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power. Profile Books, 2019.
47. Yurman, Paulina. "A Smartphone in the Nursery." Interactions 27, no. 1 (2019): 16–17.