

Activity Profiles of Independent Older Adults in Smart Homes

Proposal Defense

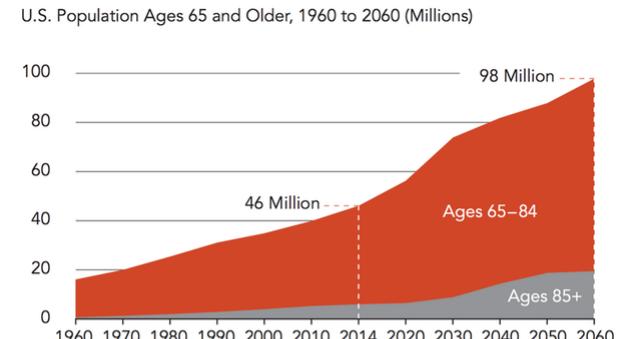
Garrick Aden-Buie

2017-09-20

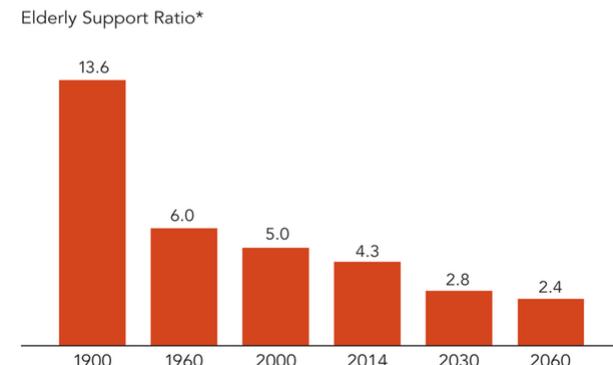
Introduction

Aging Population Demographics

- Baby boomers born 1946—1964 are driving significant demographic trends
- Number of Americans 65+ to **double** from 46M (2014) to 98M (2060)
- More older adults are divorced
- More older adults live alone
- 2/3 have multiple chronic conditions
- Increase in elder care needs, in nursing homes and for home health and informal caregivers
- Decrease in available traditional family care givers



Source: PRB analysis of data from the U.S. Census Bureau.



*Number of persons ages 18 to 64 for every person age 65 or older.

Source: PRB analysis of data from the U.S. Census Bureau.

Aging in Place

The ability to live in a residence of their choice without moving as needs for health care services change.¹

- Older adults prefer to retain their independence and remain in community based settings
- Half of older adults require help²
 - 75% of those receiving help live in houses or apartments
 - 70% receive informal help
 - 95% of informal care outside of nursing homes is from family members
- Number of 75+ without...
 - a spouse to double from 2010 to 2030 to 1.8M
 - an adult child within 10 miles to increase by factor of six³

1. Marek & Rantz (2000). pmid:[10986927](#)

2. Scommegna (2016). Today's Research on Aging: Family Caregiving

3. Ryan et al. (2012). doi:[10.1093/geront/gnr142](#)

Technology and Aging

Simple unobtrusive sensors and computing systems

Monitor older adults to support aging in place and bring piece of mind to caregivers

Acceptance by older adults and their families:

- 8 of 10 say using these devices would help them feel safer
- 46% would be interested in a system that monitors daily routine
- But only 1 of 10 currently use personal health technology devices¹



1. Barrett (2011). Healthy@ Home 2.0 <https://assets.aarp.org/rgcenter/health/healthy-home-11.pdf>

Technology in the Home

IoT, Home Security, and Home Automation

Smart devices for the home:

- Google Home
- Amazon Alexa
- Apple HomeKit
- Samsung SmartThings
- Nest, Wink, WeMo, Lutron, Hue

Enable things like:

- Open the shades when you wake up
- Turn off the lights before bed by voice
- Lock the front door when you leave home
- Turn on the A/C when you're headed home



Summary

Driving Challenge

- | Provide care for aging adults in face of demographic and cultural shifts

Summary

Driving Challenge

| Provide care for aging adults in face of demographic and cultural shifts

Goals

- Build on cost-effective home monitoring technology
- Connect older adults with health care systems and family
- **Lifestyle reassurance**
 - raise awareness of health status and changes
 - support effective, early intervention

Challenges

Sensors in the home

- Real occupants in unscripted situations performing unknown actions
- Remote sensing in low-visibility locations
- Balance between high density of sensors and cost-efficiency and acceptance

Challenges

Sensors in the home

Reliability issues

- Low-power wireless network — communication issues
- Battery powered sensors
- Human interaction with sensors¹
- Various devices, device types and manufacturers
- Non-failure related messiness

1. Hnat et al. (2011). doi:[10.1145/2070942.2070966](https://doi.org/10.1145/2070942.2070966).

Challenges

Sensors in
the home

- Inherent hierarchy of sensor data as function of floor plan
- Overlapping regions of detection
- Various degrees of temporal resolution
- Data stored out of context as discrete events

Reliability
issues

Spatio-
temporal
interactions

Other Smart Home Projects for Older Adults

- TigerPlace¹
 - Pioneer of *age-in-place* and AAL
 - 17 apartments in assisted living facility
- CASAS (ORCATECH)²
 - Over 400 homes in Portland area
 - Real-world settings with older adults, long-term
 - Limited number of sensors
- PlaceLab³
 - Live-in apartment-scale laboratory
 - MIT - Cambridge, MA
 - 100s of sensors

1. Skubic et al. (2009). doi:[10.3233/THC-2009-0551](https://doi.org/10.3233/THC-2009-0551)

2. Cook et al. (2013). doi:[10.1109/MC.2012.328](https://doi.org/10.1109/MC.2012.328)

3. Intille et al. (2005)

Proposal

Context

Maximize acceptance and cost efficiency, minimize reliability issues

- Simple set of low-cost sensors
- Prefer most reliable sensors
- Sparsely installed within the home of older adults

Proposal

Context

Can we make meaningful and timely observations of older adult's activities

- without needing labels
- without knowing floor plan or layout
- without an annotated training set
- and that works "out of the box"?

to create/enable

- Activity profiles
- Detection of changes in routine
- Early warning notification systems

Research Questions

Proposal

Context

1. *Health BOOST in The Villages*

2. Our sensor system

3. Software layers

4. Activity Profiles

5. Dissertation Proposal

Research Questions

Outline

Health BOOST

*Sensor Based Response Oriented Technology for
In-Home Monitoring of Senior Health and Well-Being*

Health BOOST in The Villages

Better Outcomes for Older Adults Using Sensor Technology

Overview

- Interdisciplinary effort involving faculty and students from College of Engineering and Public Health at USF
- Explore the use of passive wireless sensor technology in the homes of older adults
- Test a comprehensive system of sensors in real-world settings

Participants

- 55+ resident of The Villages
- Living alone in pet-free home with internet access
- Do not exhibit signs of cognitive impairment

The Villages, FL

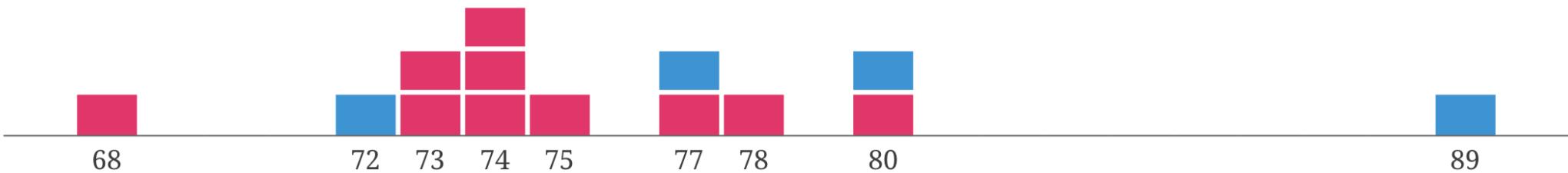
- The largest retirement community in the US: 115,000+ residents
- 30 minutes south of Ocala, 75 miles north of USF Tampa Campus
- ~50k homes, 80% occupied by at least one person 55+
- Average age of a Villager is 62 (male) and 60 (female)
- 32 square miles, 3 town squares, 10 commercial areas, 63 rec centers
- A Villager could play 30 straight days of golf, 18 holes/day

Overview of Study Participation

- 14 total participants (7 ongoing) with 5,230 total days of observation
- 12 have completed at least 6 months, 1 exited prior, 1 recently joined

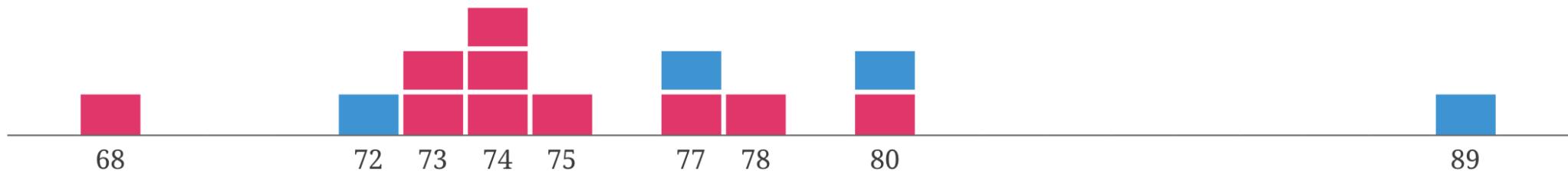
Overview of Study Participation

- 14 total participants (7 ongoing) with 5,230 total days of observation
- 12 have completed at least 6 months, 1 exited prior, 1 recently joined
- Participant gender and age at study start

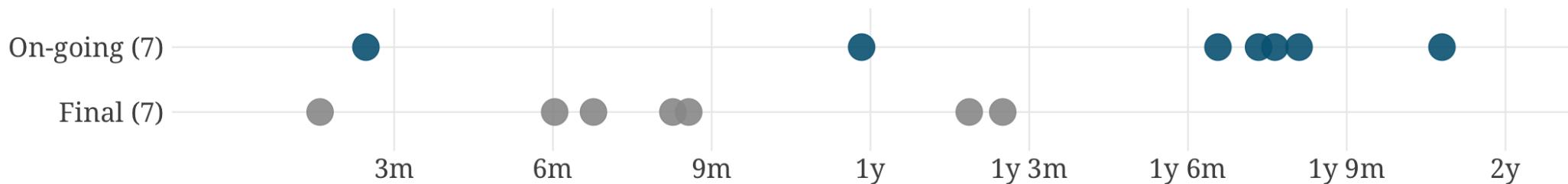


Overview of Study Participation

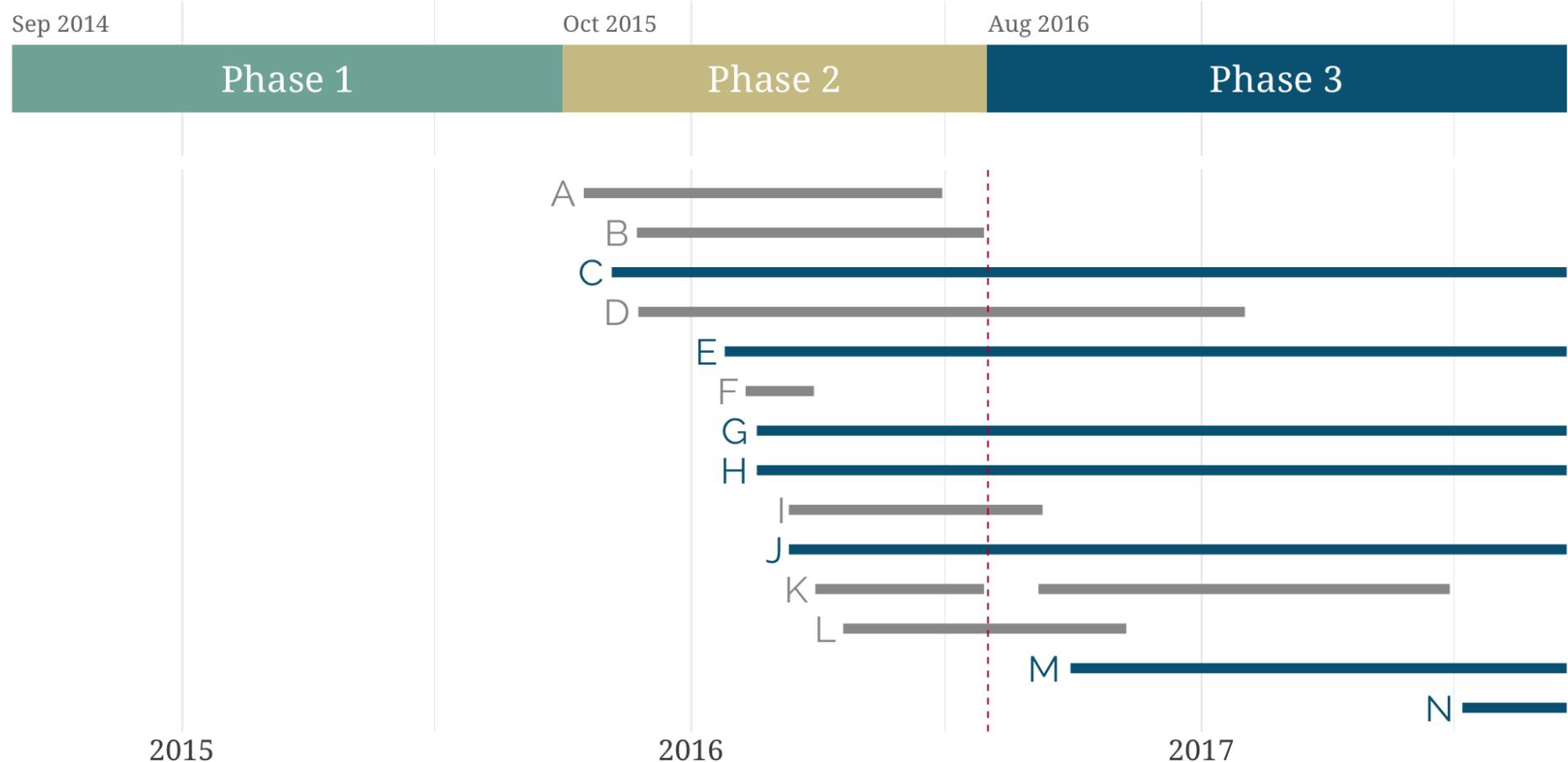
- 14 total participants (7 ongoing) with 5,230 total days of observation
- 12 have completed at least 6 months, 1 exited prior, 1 recently joined
- Participant gender and age at study start



- Days of participation in study



Timeline



Our system

Sensors

Motion



Sensors

Motion



Contact



Sensors

Motion



Contact



Power



Sensors

Motion



Contact



Power



Water



Sensors

Motion



Contact



Power



Water

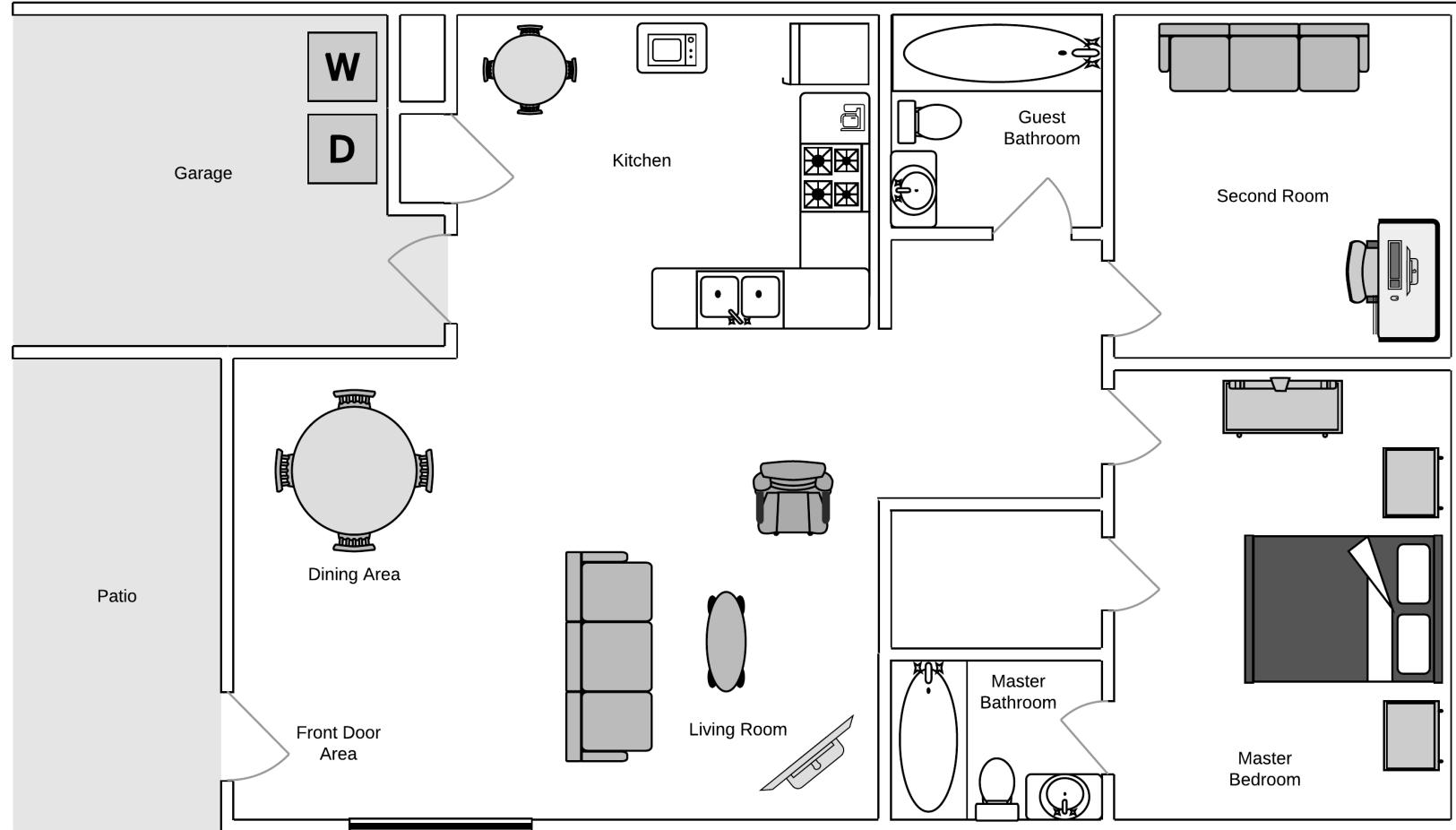


System

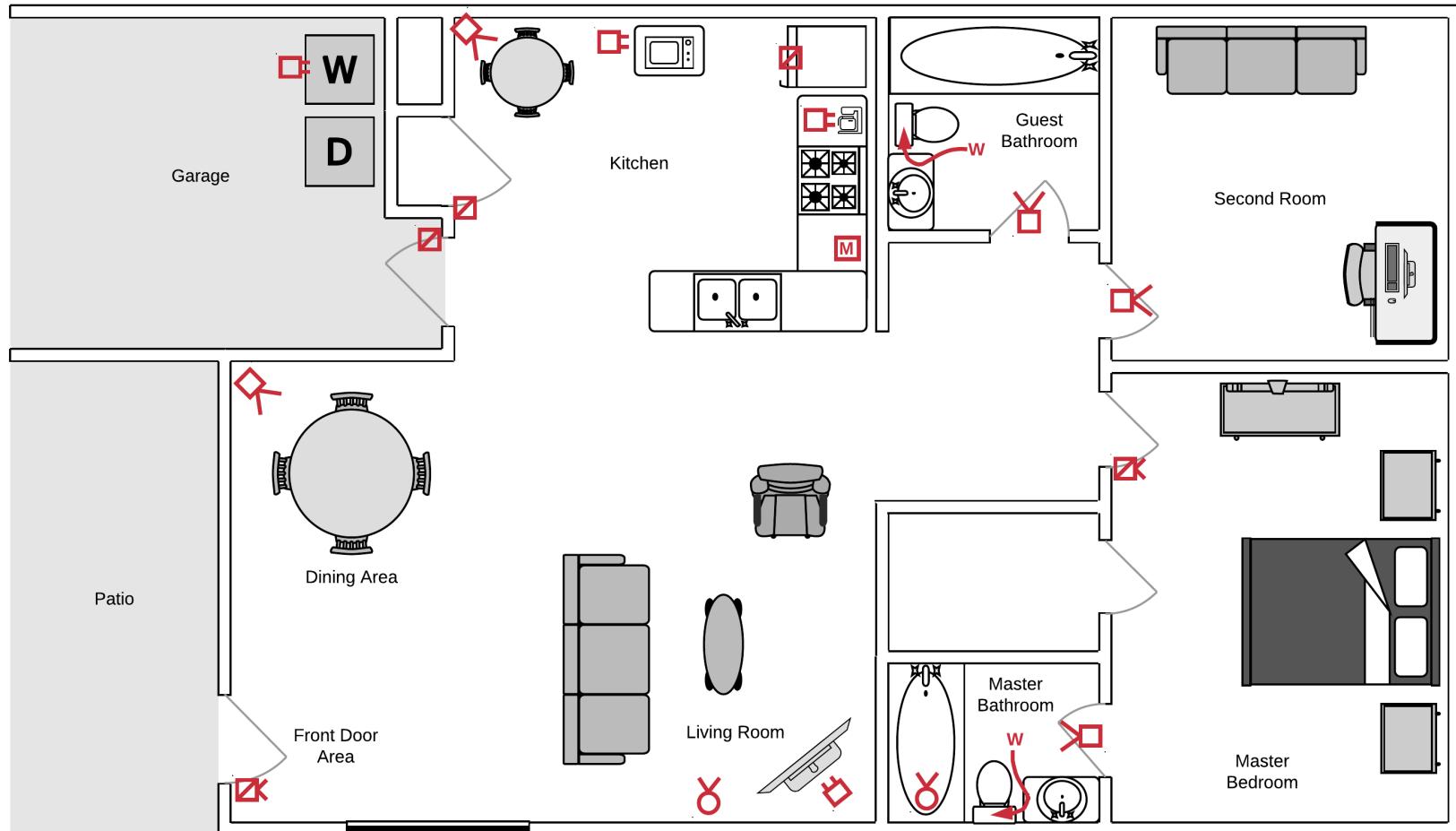


Bed/Seat Mats

Home Layout



Home Layout



■ AeonLabs
Contact

■ Ecolink
Motion

■ AeonLabs
Multi

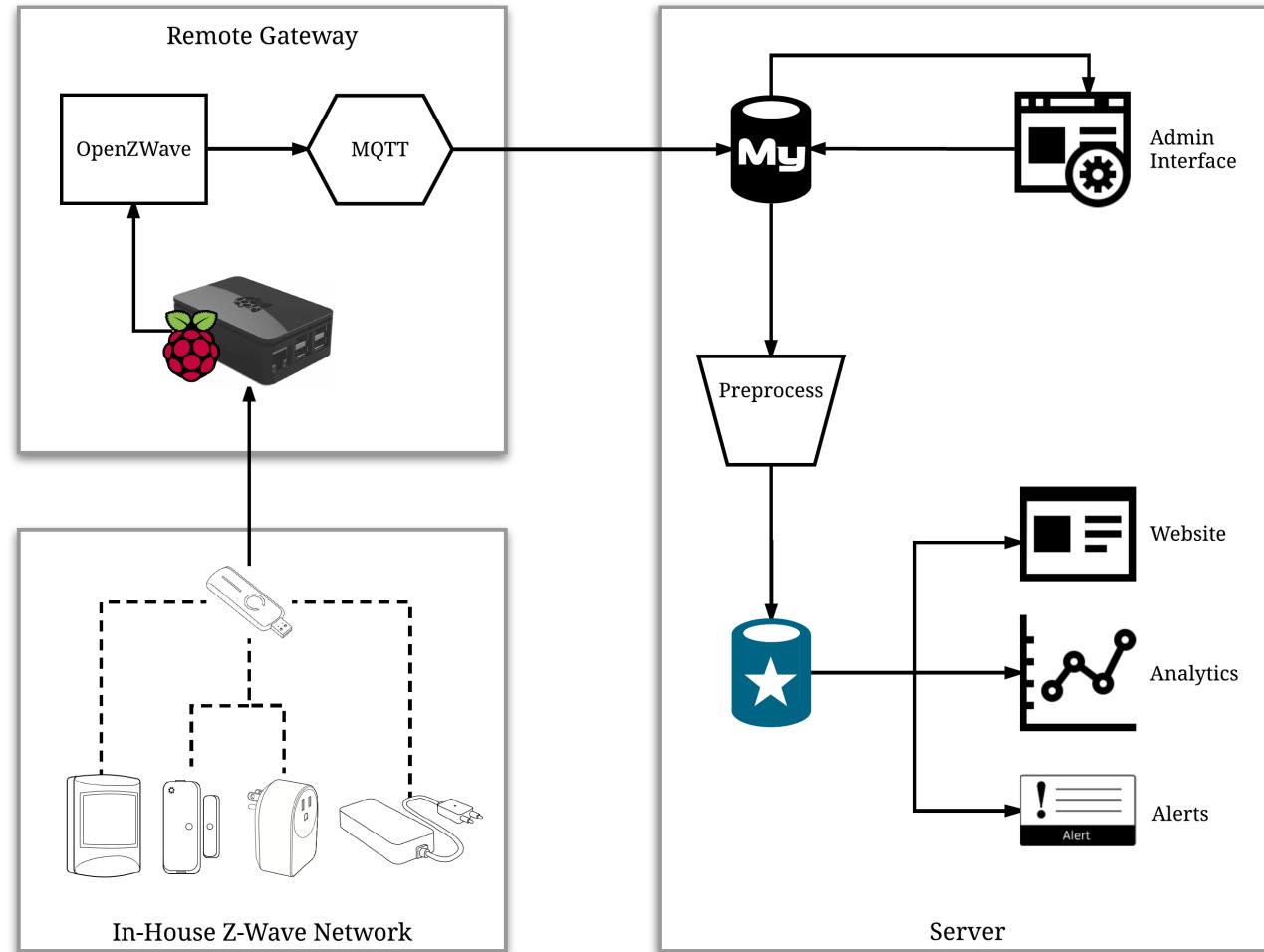
■ Zipato
Multi

■ AeonLabs
Appliance

■ Medicine
Container

■ AeonLabs
Water

System architecture



Software layers

Data Collection

- `zrayd` — An OpenZWave client in C++, collects sensor data
- `zmonitor` — Monitor daemons, services, system state, OTA updates
- `mqtt` — Lightweight message passing service for real-time transfer of sensor events
- `zcollector` — Python script on server processes messages and associates with physical sensors
- `zproc` — Micro-batch preprocessing of sensor data (R scripts)
- `notiproc` — Framework and daemon for near real-time alert processing (R scripts)

Databases

- `zray` — Raw data warehouse, **53 million** sensor events from 5,516 sensor streams
- `zproc` — Preprocessed data, batch updated and recomputed on config changes, reduced to **6 - 17M** events

Admin Interface (System configuration)

- Inventory Management
- Installation Preparation
- System Configuration
- Planning and Review
- Maintenance Visits
- Data Export

The screenshot shows a web-based administration interface for a system named 'Wilson Admin'. The top navigation bar includes links for 'Wilson Admin', 'System Info', 'View', 'Add/Edit', 'Workflow', 'Maintenance', and 'Export'. The main content area is divided into several sections. At the top, there are four large boxes: 'Uptime' (6.8d), 'Messages stored' (200), 'Messages received' (2,668,181), and 'Messages sent' (4,411,044). Below these are four more boxes: 'Database' (zray), 'Last Backup' (2017-02-28 12:04:01), 'Disk Usage' (50%), and 'CPU' (8.2%). The bottom half of the screen displays a grid of asset inventories. The first row contains four green boxes: 'hctest-rp-208' (AN Office Test), 'an-rp-90' (House004), 'an-rp-282' (House006), and 'an-rp-284' (House008). The second row contains four white boxes: 'an-rp-285' (House010), 'an-rp-229' (House013), 'usf-rp-230' (House014), and 'an-rp-286' (House017).

Admin Interface (System configuration)

Wilson Admin System Info View Add/Edit Workflow Maintenance Export

Plan New Installation

House * New House

Add new location

Room * Bedroom, Master

Exterior Room
Can occupant enter this room from outside the house?

Device Type Aeon Labs - Water Sensor

On Hand: 40

Device AN.AL.WS.82

Install Purpose Toilet, Master

Install Notes Installation instructions, e.g. "Pantry"

+ Add ? Help

Planned Devices

Device	Location	Install Purpose	Room	Exterior	Exit	Install Notes
USF.RP.634	New House	0 - System	No	No		
AN.AL.ZS.157	New House	0 - System	No	No		
USF.AL.DW.189	New House	Front Door	Entrance	No	No	
USF.PM.147	New House	Sofa	Living Room	No	No	
USF.AL.MS.509	New House	Living Room	Living Room	No	No	
AN.AL.SS.80	New House	Television, Living Room	Living Room	No	No	
USF.AL.DW.190	New House	Fridge	Kitchen	No	No	
USF.AL.DW.191	New House	Pantry	Kitchen	No	No	
USF.AL.DW.192	New House	Garage Door	Kitchen	No	No	
AN.AL.SS.129	New House	Blender	Kitchen	No	No	
AN.AL.SS.130	New House	Coffee Machine	Kitchen	No	No	
AN.AL.SS.131	New House	Microwave	Kitchen	No	No	
AN.AL.SS.132	New House	Television, Bedroom	Bedroom, Master	No	No	
USF.PM.220	New House	Bed	Bedroom, Master	No	No	
USF.ZP.6	New House	Bedroom, Master	Bedroom, Master	No	No	
AN.ZP.MS.105	New House	Bathroom, Master	Bedroom, Master	No	No	
USF.AL.MS.511	New House	Shower	Bedroom, Master	No	No	

Showing 1 to 17 of 17 entries

+ Save List Clear List

Wilson Admin System Info View Add/Edit Workflow Maintenance Export

Prepare System

House Key b31f3bab

Save (17)

Choose House New House

Download Device Pull Form

Save	Device	Make	Model	Install Room	Status	Z-Node ID	Notes
<input checked="" type="checkbox"/>	AN.AL.ZS.157	Aeon Labs	Z-Stick S2	0 - System	Prepared	0	
<input checked="" type="checkbox"/>	USF.RP.634	Raspberry Pi	3	0 - System	Prepared	0	Used disk image 3ab45f
<input checked="" type="checkbox"/>	USF.AL.DW.189	Aeon Labs	Door/Window Sensor (2nd Edition)	Entrance	Prepared	1	
<input checked="" type="checkbox"/>	AN.AL.SS.80	Aeon Labs	Smart Switch (2nd Edition)	Living Room	Prepared	2	
<input checked="" type="checkbox"/>	USF.AL.MS.509	Aeon Labs	MultiSensor Gen5	Living Room	Prepared	3	
<input checked="" type="checkbox"/>	USF.PM.147	CREATE Health	Seat Mat (D5B29)	Living Room	Prepared	4	Repaired minor tear in cover
<input checked="" type="checkbox"/>	AN.AL.SS.129	Aeon Labs	Smart Switch (2nd Edition)	Kitchen	Prepared	5	

Admin Interface (System configuration)

Device Pull Form

Aeon Labs - Door/Window Sensor (2nd Edition)

Found	Device ID	Install Room	Status	Install Notes
USFAL.DW.199	Entrance	Allocated		
USFAL.DW.190	Kitchen	Allocated		
USFAL.DW.191	Kitchen	Allocated		
USFAL.DW.192	Kitchen	Allocated		

Aeon Labs - MultiSensor Gen5

Found	Device ID	Install Room	Status	Install Notes
USFAL.MS.509	Living Room	Allocated		
USFAL.MS.511	Bedroom, Master	Allocated		

Aeon Labs - Smart Switch (2nd Edition)

Found	Device ID	Install Room	Status	Install Notes
ANAL.SS.80	Living Room	Allocated		
ANAL.SS.129	Kitchen	Allocated		
ANAL.SS.130	Kitchen	Allocated		
ANAL.SS.131	Kitchen	Allocated		
ANAL.SS.132	Bedroom, Master	Allocated		

CREATE Health - Queen Bed Mat (DSB29)

Found	Device ID	Install Room	Status	Install Notes
USFPM.220	Bedroom, Master	Allocated		

CREATE Health - Seat Mat (DSB29)

Found	Device ID	Install Room	Status	Install Notes
USFPM.147	Living Room	Allocated		

Raspberry Pi -

Found	Device ID	Install Room	Status	Install Notes
USFRPi.04	0 - System	Allocated		

Configure Sensors

Sensors

Z-Node ID	Display	Sensor	Alias
10	577	10 Temperature	Temperature in Entrance
10	578	10 Sensor Binary 1	Opened Front Door
10	572	1 Luminance	Light Levels in Front Door
10	573	1 Battery	
10	574	1 Wakeup	
10	576	1 Basic	In Front Door Area
10	575	0 Sensor Binary 0	
10	579	0 Sensor Binary 2	
10	710	0 Wake Up	
10	711	0 Minimum Wake-up Interval	
10	712	0 Maximum Wake-up Interval	
10	713	0 Default Wake-up Interval	
10	714	0 Wake-up Interval Step	
10	715	0 Library Version	
10	716	0 Protocol Version	
10	717	0 Application Version	

Sensor Configuration

Sensor Type: Sensor Binary 1

Alias: Opened Front Door

Sensor Class: Binary

Reporting Unit: count

Operator: =

On Value: 1

Unit:

Display Level: 10

Showng 1 to 16 of 16 entries

Admin Interface (System configuration)

The screenshot shows the 'Installation Workflow' section of the admin interface. It includes fields for 'Status' (Installed), 'Locations' (New House), 'Z-Node ID' (Loading...), and a note field with the date 2017-02-21. A table lists 12 devices with columns: Device ID, Install Purpose, Install Room, Z-Node ID, Status, Instructions, and Device Type. The table shows various devices like Aeon Labs - Z-Stick S2, Raspberry Pi - 3, and Aeon Labs - Door/Window Sensor (2nd Edition).

Device ID	Install Purpose	Install Room	Z-Node ID	Status	Instructions	Device Type
1 ANAL.ZS.157		0 - System	0	Prepared		Aeon Labs - Z-Stick S2
2 USF.RP.634		0 - System	0	Prepared		Raspberry Pi - 3
3 USF.AL.DW.189	Front Door	Entrance	1	Prepared		Aeon Labs - Door/Window Sensor (2nd Edition)
4 USF.AL.MS.509	Living Room	Living Room	3	Prepared		Aeon Labs - MultiSensor Gen5
5 ANAL.SS.80	Television, Living Room	Living Room	2	Prepared		Aeon Labs - Smart Switch (2nd Edition)
6 USF.PM.147	Sofa	Living Room	4	Prepared		CREATE Health - Seat Mat (DSB29)
7 USF.AL.DW.190	Fridge	Kitchen	8	Prepared		Aeon Labs - Door/Window Sensor (2nd Edition)
8 USF.AL.DW.191	Pantry	Kitchen	9	Prepared		Aeon Labs - Door/Window Sensor (2nd Edition)
9 USF.AL.DW.192	Garage Door	Kitchen	10	Prepared		Aeon Labs - Door/Window Sensor (2nd Edition)
10 ANAL.SS.129	Blender	Kitchen	5	Prepared		Aeon Labs - Smart Switch (2nd Edition)
11 ANAL.SS.130	Coffee Machine	Kitchen	6	Prepared		Aeon Labs - Smart Switch (2nd Edition)
12 ANAL.SS.131	Microwave	Kitchen	7	Prepared		Aeon Labs - Smart Switch (2nd Edition)

The screenshot shows the 'Export Data' page. It includes fields for 'Source Data Type' (Pre-processed) and 'Output Format' (Excel). Below these are sections for 'Data Options' (Select House) and 'Date Range' (2017-01-30 through 2017-02-27). A 'Minimum Display Level' slider is set to 10. At the bottom are 'Prepare Data' and 'Download Data' buttons.

Data Preprocessing

Raw

sensor_id	event_time	value
618	2017-07-11 20:22:22	0.000
618	2017-07-11 20:22:33	1.000
612	2017-07-11 20:23:19	2.233
612	2017-07-11 20:23:22	28.806
612	2017-07-11 20:23:25	50.397
612	2017-07-11 20:32:43	26.411
612	2017-07-11 20:32:46	28.425
612	2017-07-11 20:32:49	30.159
612	2017-07-11 20:32:55	32.124
618	2017-07-11 20:32:56	0.000

Preprocessed

sensor_id	start_time	end_time	value	duration
618	20:22:33	20:26:18	1	223
612	20:23:22	20:29:07	1	345
618	20:26:18	20:28:58	0	160
618	20:28:58	20:32:56	1	238
612	20:29:07	20:29:10	0	2
612	20:29:10	20:37:16	1	486
618	20:32:56	20:38:23	0	326

Data Preprocessing

Metadata

id	alias	install_room	devid	model	manufacturer	type
612	Using Television	Living Room	AN.AL.SS.133	Smart Switch (2nd Edition)	Aeon Labs	Power
618	In Living Room	Living Room	USF.EL.MS.216	Motion Sensor	Ecolink	Sensor Binary 0

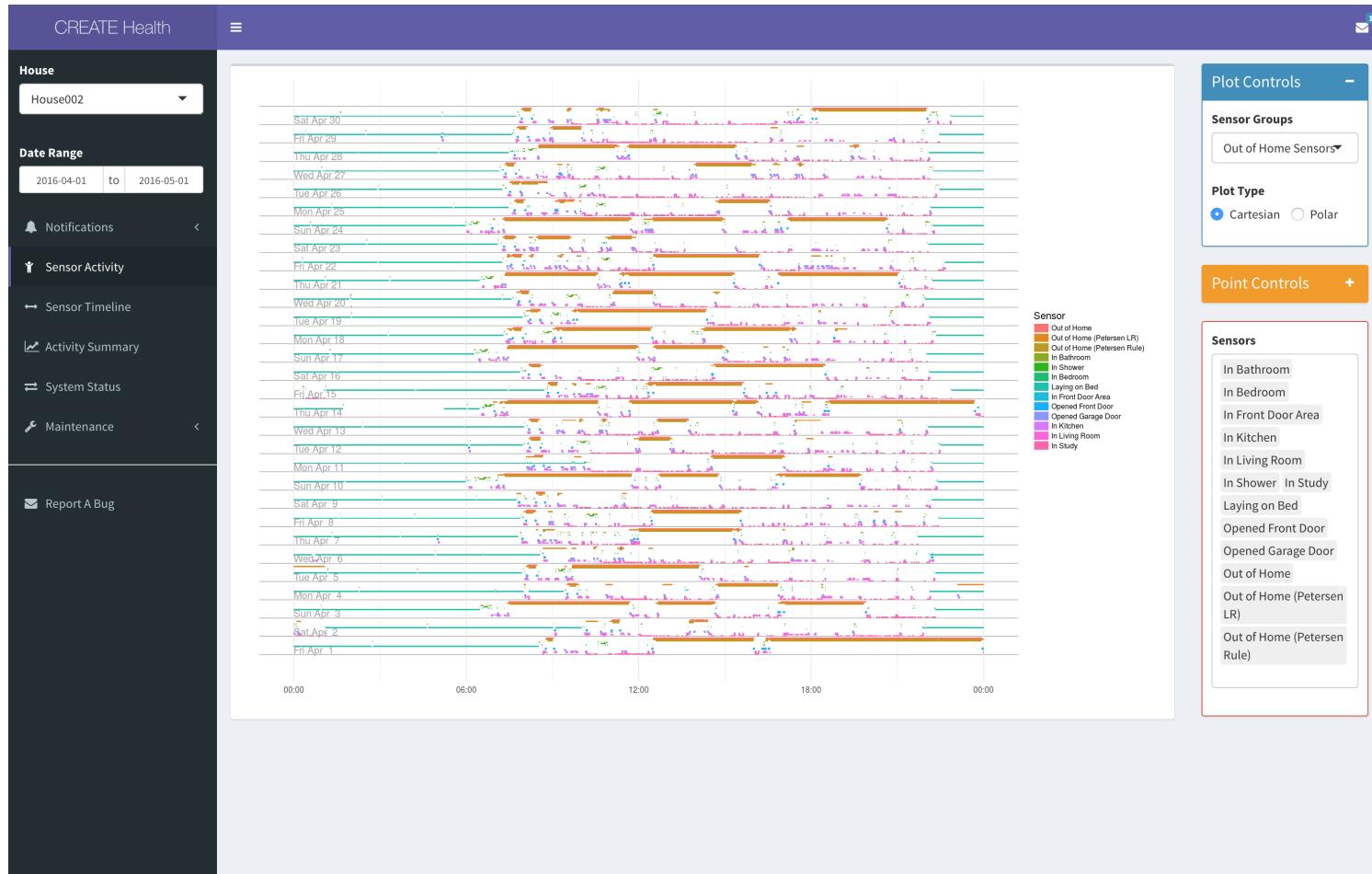
Data Preprocessing

- Enforce ordering of events by timestamp
- Remove duplicate and non-state-change events
- **Binary:** Convert values to state and reduce again
- **Value:** Compress old values
- Monitor run state and current position in event data stream

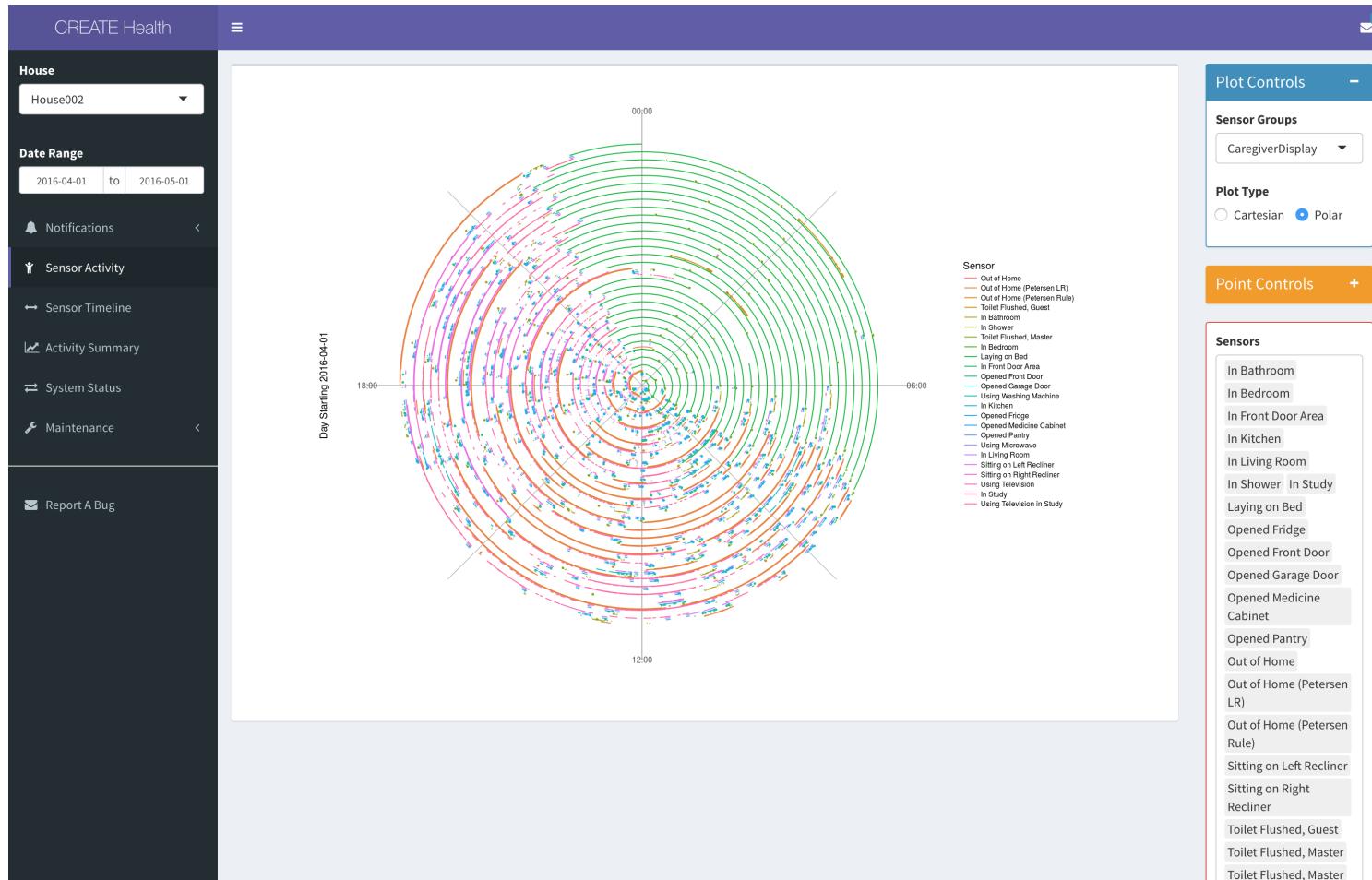
Modes

- **Micro-batch:** Process only new events since last run
- **Full rebuild:** Rebuild entire preprocessed database
- **Add/rebuild/remove individual:** Update preprocessed data on config change

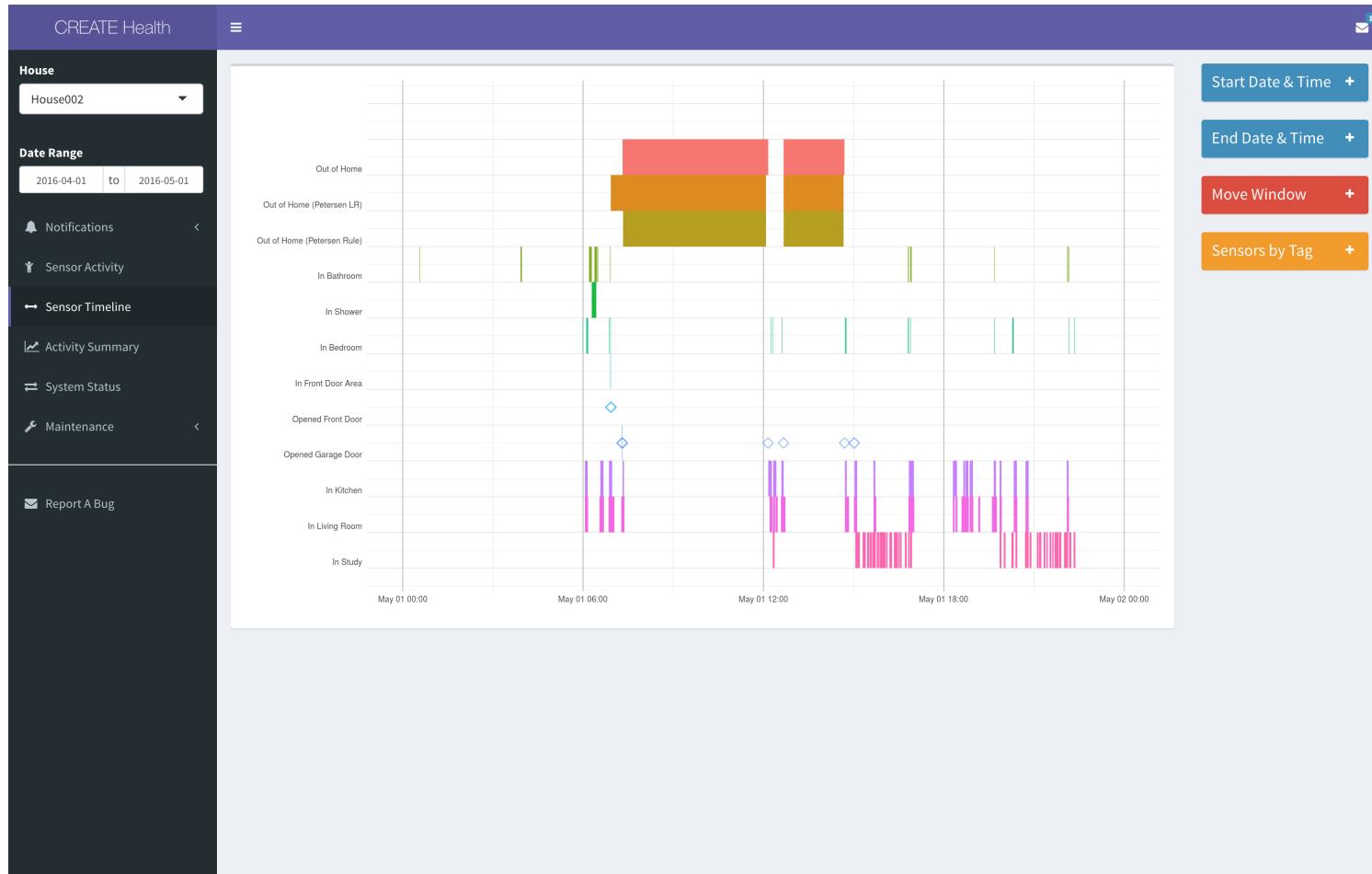
Data Visualization and Exploration



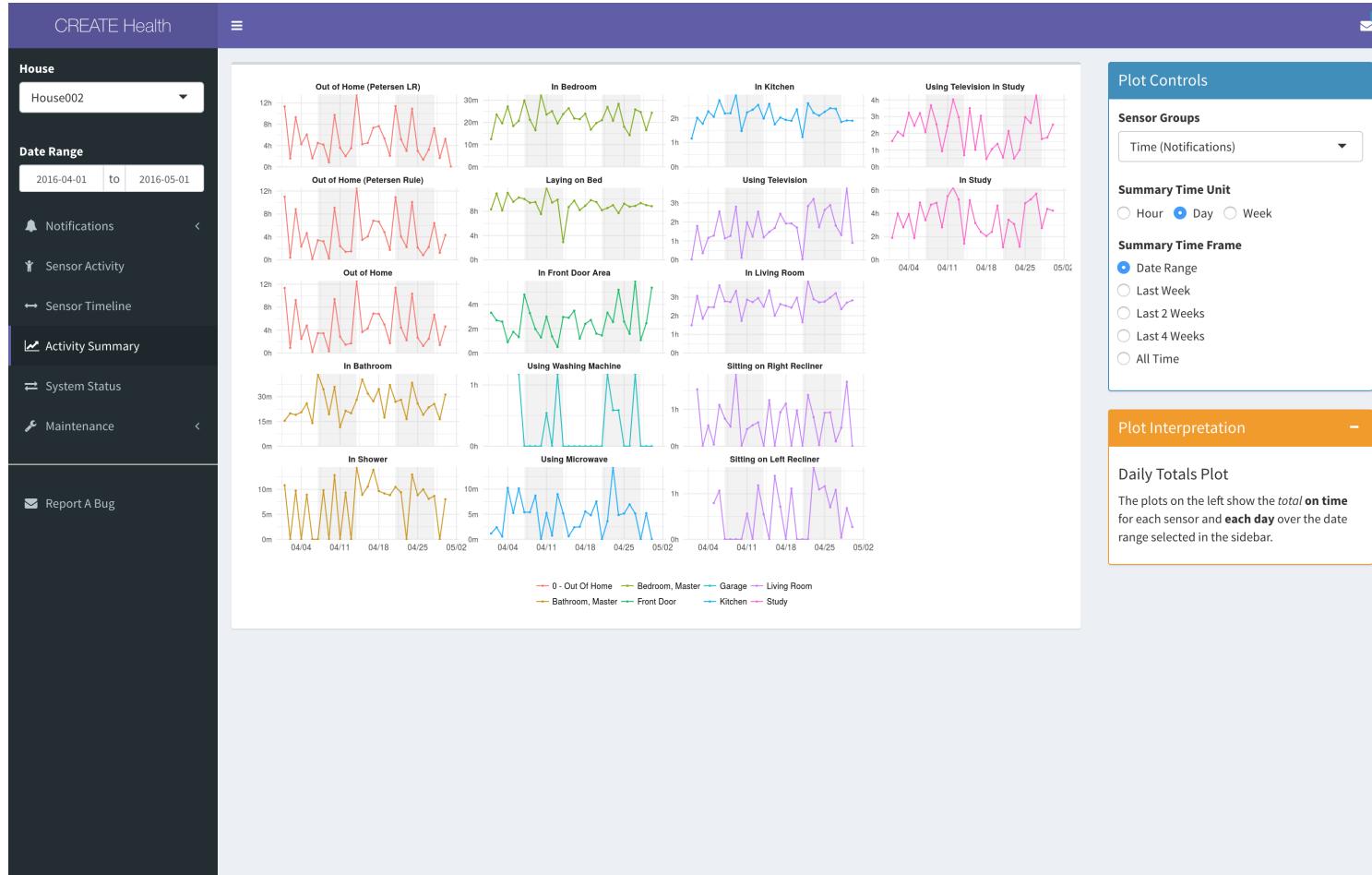
Data Visualization and Exploration



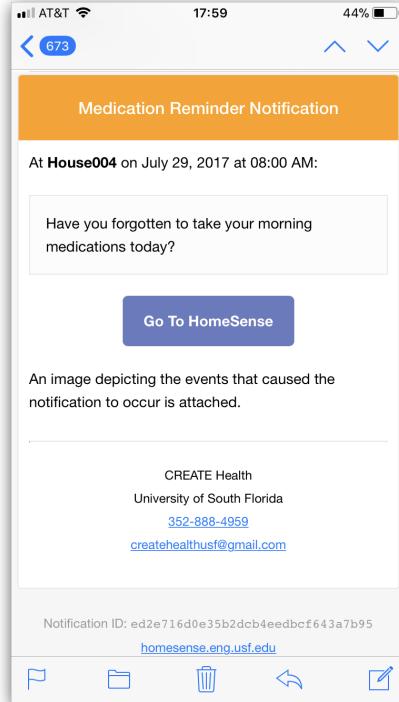
Data Visualization and Exploration



Data Visualization and Exploration



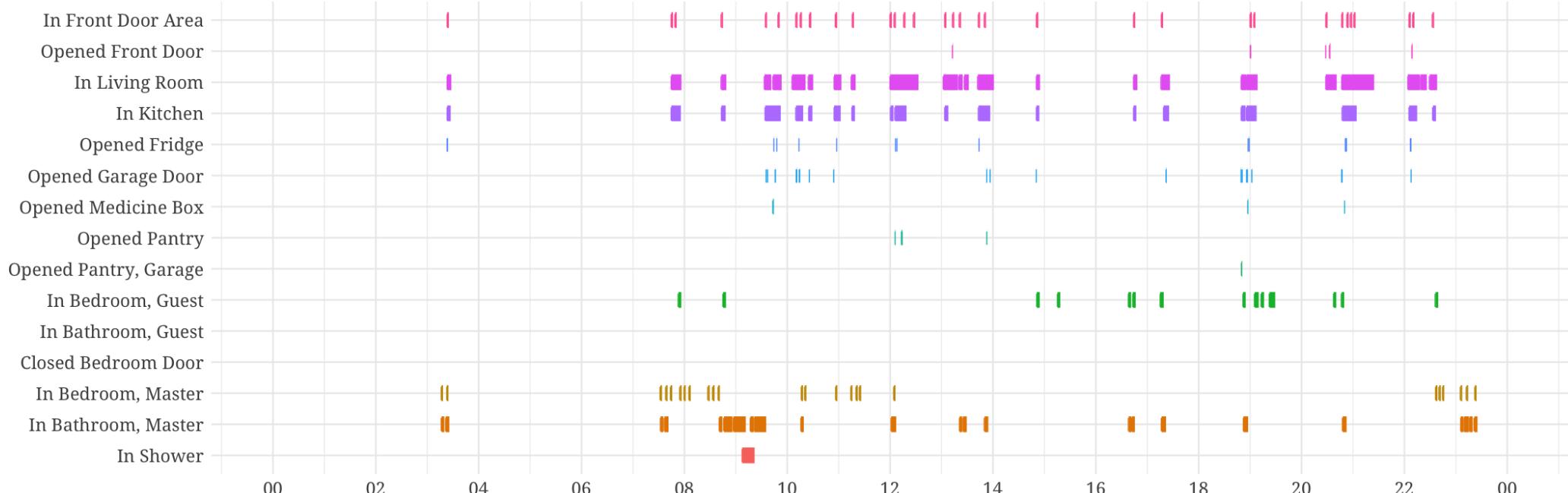
Notification System



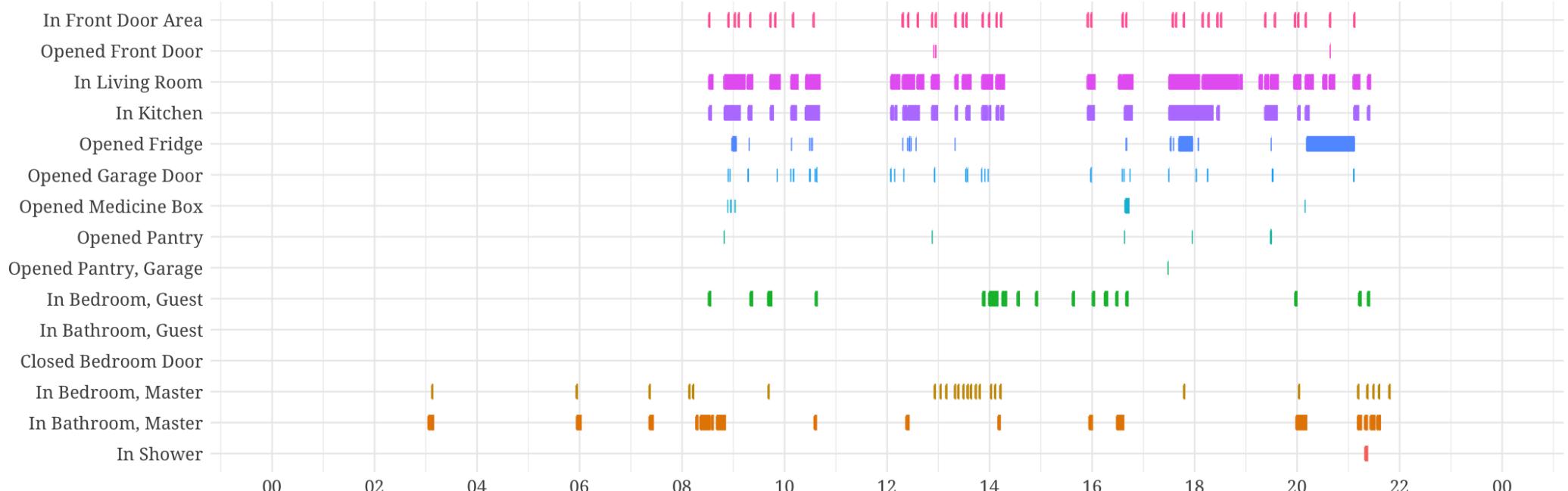
- Real-time alert processing to deliver timely notifications
- Both a processing script and a framework
- As a framework it provides
 - Ability to run **arbitrarily complex alert** state evaluation
 - A comprehensive design pattern for deciding **when, how and for whom**
 - Easy access to alert **actions** (email, text message, etc.)
 - A **simulation mode** for post-hoc analysis of models and methods

Activity Profiles

Example Day of Sensor Activity



Example Day of Sensor Activity



Activity Profiles Background

n-grams

- Bag-of-words document summarization model — Zhang et al. (2010)
- Text categorization and "language profiles" — Cavnar and Trenkle (1994)
- Text prediction systems — Garay-Vitoria and Abascal (2006)
- Automatic generation of summaries — Lin and Hovy (2003)
- Word-embedding method (word2vec) — Goldber and Levy (2014)

Pattern and Motif learning

- Sequential Aggregate Approximation (SAX) — Lin et al. (2007)
- Periodic outlier detection in time-serier sequences — Rasheed and Alhajj (2014)

Anamolous Activity Detection

- Detect and explain anamolous activities — Hamid et al. (2005)

Routine Discovery in Smart Homes

- Unsupervised routine detection of older adults using SAX — Yin et al. (2015)

n-grams

corpus

n-grams

corpus

n-grams

corpus

n-grams

corpus

n-grams

corpus

n-grams

-	c	o	r	p	u	s	-
c	co	or	rp	pu	us	s	
co	cor	orp	rpu	pus	us		
cor	corp	orpu	rpus	pus			
corp	corpu	orpus	rpus				
corpu	corpus	corpus					
corpus	corpus						
corpus							

n-grams

-	c	o	r	p	u	s	-
c	co	or	rp	pu	us	s	
co	cor	orp	rpu	pus	us		
cor	corp	orpu	rpus	pus			
corp	corpu	opus	rus				
corpu	corpus	opus					
corpus	opus						
corpus							

n-grams

1. o r p u

2. _c or rp pu s_

3. _co orp rpu us_

4. _cor orpu pus_

5. _corp rpus_

6. _corpu orpus_

7.

8. _corpus_

Sensor Events as Event-Strings

Sensor Inclusion

Keep only *active* events that indicate interaction or movement within the environment

Motion: Keep only ON activation events

Contact: Keep both ON and OFF events

In Front Door Area	In Study	Opened Medicine Drawer
In Living Room	In Bedroom, Guest	Opened Medicine Cabinet
In Kitchen	In Bedroom, Guest 2	Opened Medicine Closet
In Dining Area	In Bathroom, Guest	Opened Medicine Box
In Bedroom, Master	In Bath, Guest	Opened Garage Door
In Bathroom, Master	In Sewing Room	Opened Front Door
In Shower	Opened Pantry, Garage	Opened Fridge
In Office	Opened Pantry	Closed Bedroom Door

Sensor Events as Event-Strings

Sensor Inclusion

sensor_id	alias	start_time	value
3807	In Bathroom, Master	2017-07-19 03:21:28	1
3772	In Bedroom, Master	2017-07-19 03:22:44	1
3910	In Living Room	2017-07-19 03:23:09	1
3613	In Front Door Area	2017-07-19 03:23:12	1
3721	In Kitchen	2017-07-19 03:23:13	1
5255	Opened Fridge	2017-07-19 03:23:22	1
5255	Opened Fridge	2017-07-19 03:23:29	0
5255	Opened Fridge	2017-07-19 03:23:53	1
5255	Opened Fridge	2017-07-19 03:23:59	0
3772	In Bedroom, Master	2017-07-19 03:24:44	0
3613	In Front Door Area	2017-07-19 03:25:12	0

Sensor Events as Event-Strings

Sensor
Inclusion

Standardizing
Names

Global

- `In Living Room` → `InLivingRoom`
- `OpenedFrontDoor` → `OpenedFrontDoor` and `!OpenedFrontDoor`
- `OpenedMedicineCont` for medicine *box, cabinet, drawer*, etc.

Specific adjustments

- `InShower` for primary bathing location
- Activity rooms and guest bedrooms: `InSecondRoom` and `InBedroomGuest`

Sensor Events as Event-Strings

Sensor Inclusion Pauses are inserted when no activity is observed
Timestamp of **15 minutes** after last event before pause

Standardizing Names

Pauses

Pause Type	Time Between Events
Short	$15 \leq x < 60$ minutes
Medium	$1 \leq x < 3$ hours
Long	$3 \leq x$ hours

Sensor Events as Event-Strings

Sensor
Inclusion

Standardizing
Names

Pauses

Dictionary

Motion	Vowel	Active	Letter	Pause	Separator
InFrontDoorArea	a	ClosedBedroomDoor	B	PauseLong	3
InLivingRoom	A	!ClosedBedroomDoor	b	PauseMedium	2
InDiningArea	e	OpenedFridge	D	PauseShort	1
InKitchen	E	!OpenedFridge	d		
InBathroomMaster	i	OpenedFrontDoor	F	PauseLong	⌚
InBedroomMaster	I	!OpenedFrontDoor	f	PauseMedium	. _
InSecondRoom	o	OpenedGarageDoor	G	PauseShort	_
InShower	O	!OpenedGarageDoor	g		
InBedroomGuest	u	OpenedMedicineCont	M		
InBathroomGuest	U	!OpenedMedicineCont	m		
		OpenedPantry	P		
		!OpenedPantry	p		

Sensor Events as Event-Strings

Sensor
Inclusion

Standardizing
Names

Pauses

Dictionary

Original

InBedroomMaster	InBathroomMaster	InBathroomMaster	
InBedroomMaster	InLivingRoom	InFrontDoorArea	InKitchen
OpenedFridge	!OpenedFridge	OpenedFridge	!OpenedFridge
PauseLong	InBedroomMaster	InBathroomMaster	InBathroomMaster
InBedroomMaster	InBedroomMaster	InLivingRoom	InFrontDoorArea
InKitchen			

Encoded

I	i	i	I	A	a	E	D	d	D	d	3	I	i	i	I	I	A	a	E
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Event-String Example

IiiIAaEDdDd3IiiIIAaEaoIII1IIIiAaEoii0iiAEaGgGgAMmDdGgGgDda1AaEGgGgGgDdGgGgaiIIAEaGg1GEAgaIDd1IAEaII1AaEiIaEPpDdDdPpPpa1AaEaFfAaiiA1AaEDaiGgPpGg1GEAgao1o1oiioAaE1oAaiEGg1GAEgPGgoiAEGgGgMmdDdDdaFfFfGgao001AaFFFfooAaGgGEgiMmDdDdDdaaa1AaEDdDdDGgFfaAAaEoIII1IiiIiiI3

[A] = Living Room, [E] = Kitchen, [I] = Bedroom, [i] = Bathroom (M), [U] = Bathroom (G), [a] = Near Front Door, [o] = 2nd Room

[Dd] = Fridge, [Ff] = Front Door, [Gg] = Garage Door, [Pp] = Pantry, [Mm] = Med Container

Event-String Example

IiiIAaEDdDd**3**IiiIIAaEaoIII**1**IIIiAaEoii0iiAEaGgGgAMmDdGgGgDda**1**AaEGgGgGgDdGgGgaiIIAEaGg**1**GEAgaIDd**1**IAEaII**1**AaEiIaEPpDdDdPpPpaa**1**AaEaFfAaiiA**1**AaEDaiGgPpGg**1**GEAgao**1**o**1**oiioAaE**1**oAaiEGg**1**GAEgPGgoiAEGgGgMmdDdDdaFfFfGgaooo**1**AaFFFfooAaGgGEgiMmDdDdDdaaa**1**AaEDdDdDGgFfaAAaEoIII**1**IiiIiiI**3**

[A] = Living Room, [E] = Kitchen, [I] = Bedroom, [i] = Bathroom (M), [U] = Bathroom (G), [a] = Near Front Door, [o] = 2nd Room

[Dd] = Fridge, [Ff] = Front Door, [Gg] = Garage Door, [Pp] = Pantry, [Mm] = Med Container

Event-String Example

_IiiIAaEDdDd.
>IiiIIAaEaoIII IIIiAaEoii0iiAEaGgGgAMmDdGgGgDda
AaEGgGgGgDdGgGgaiIIAEaGg GEAgalDd IAEaII
AaEiIaEPpDdDdPpPpaa AaEaFfAaiiA AaEDaiGgPpGg GEAgao o
oioAaE oAaiEGg GAEGPGgoiAEgGgMmdDdDdaFFFgaaaa
AaFFFfooAaGgGEgiMmDdDdDdDdaaa AaEDdDdDGgFfaAAaEoIII
IiiIiiI.
>_

[A] = Living Room, [E] = Kitchen, [I] = Bedroom, [i] = Bathroom (M), [U] = Bathroom (G), [a] = Near Front Door, [o] = 2nd Room

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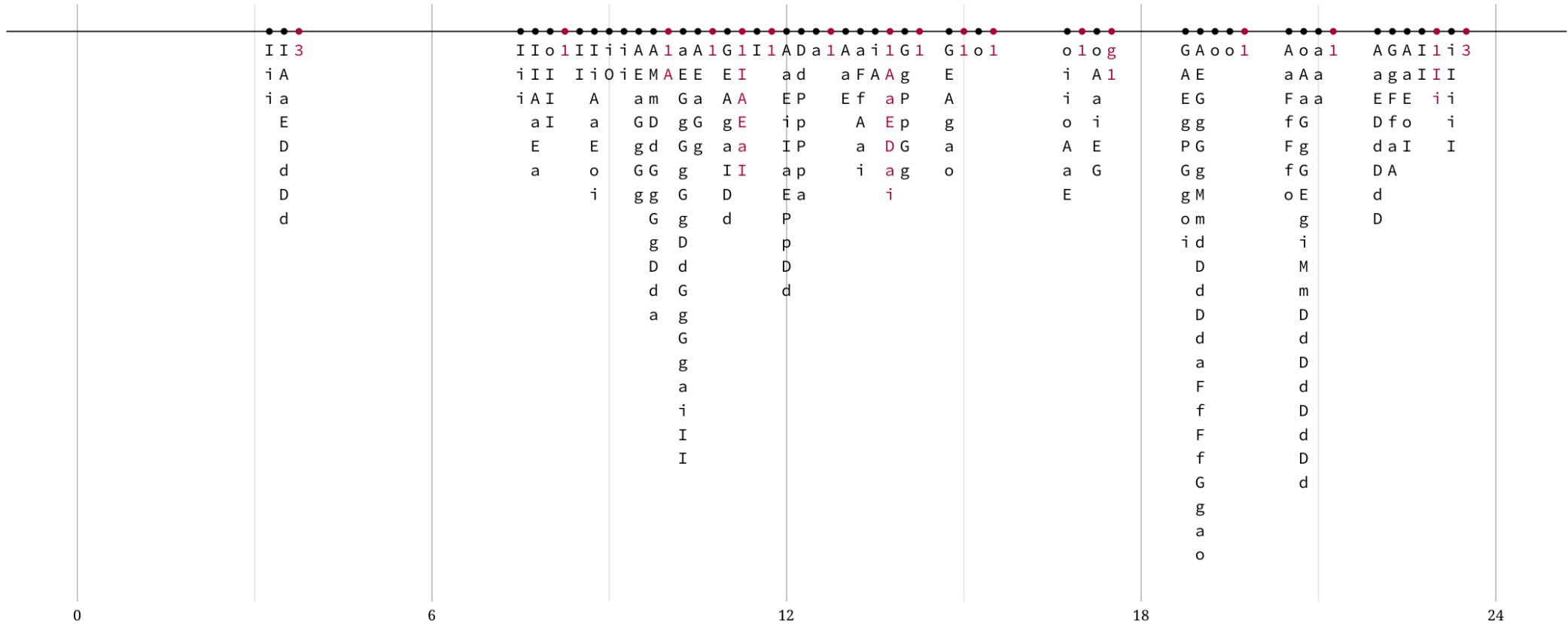
Event-String Example

_IiiIAaEDdDd.
>IiiIIAaEaoIII IIIiAaEoii0iiAEaGgGgAMmDdGgGgDda
AaEGgGgGgDdGgGgaiIIAEa**Gg GEAg**aIDd IAEaII
AaEiIaEPpDdDdPpPpaa AaEaFfAaiiA AaEDaiGgPp**Gg GEAg**ao o
oioAaE oAaiE**Gg GAEG**PGgoiAE^GgGgMmdDdDdaFfFfGgaooo
AaFFFfooAaGgGEgiMmDdDdDdDdaaa AaEDdDdDGgFfaAAaEoIII
IiiIiI.
>_

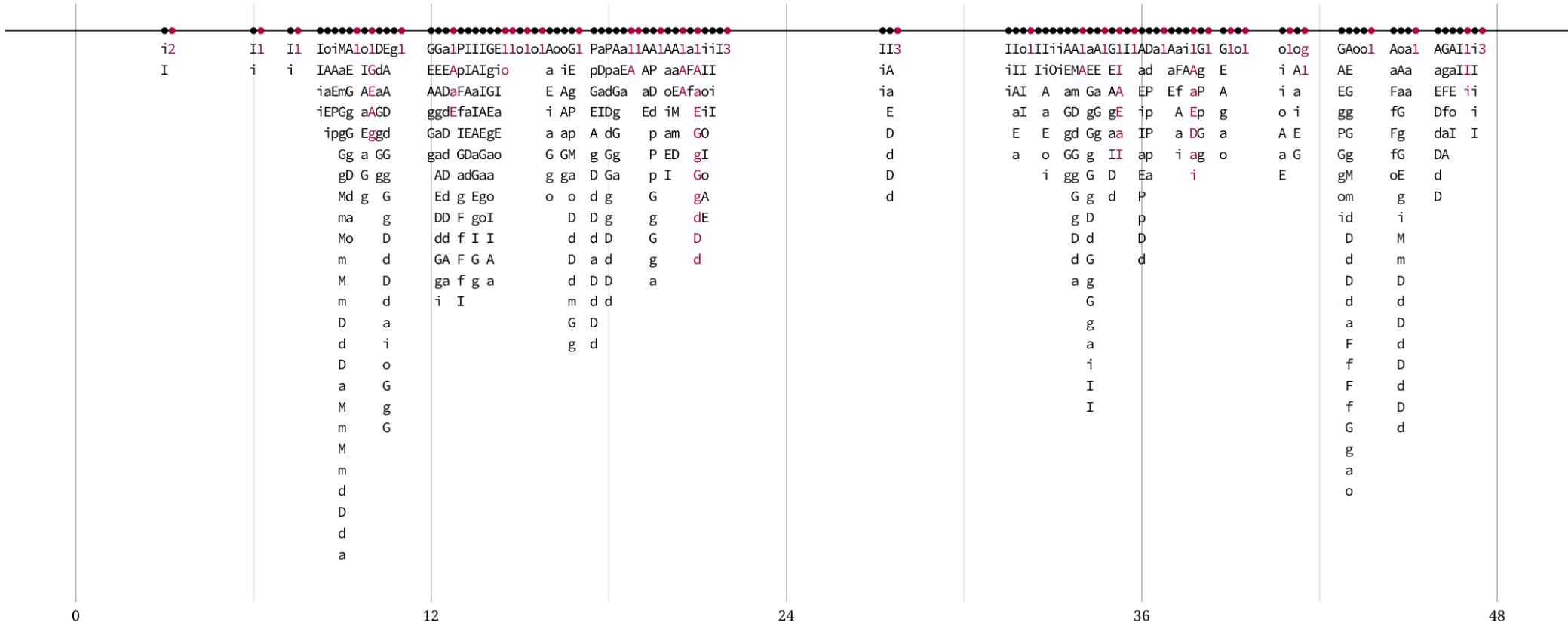
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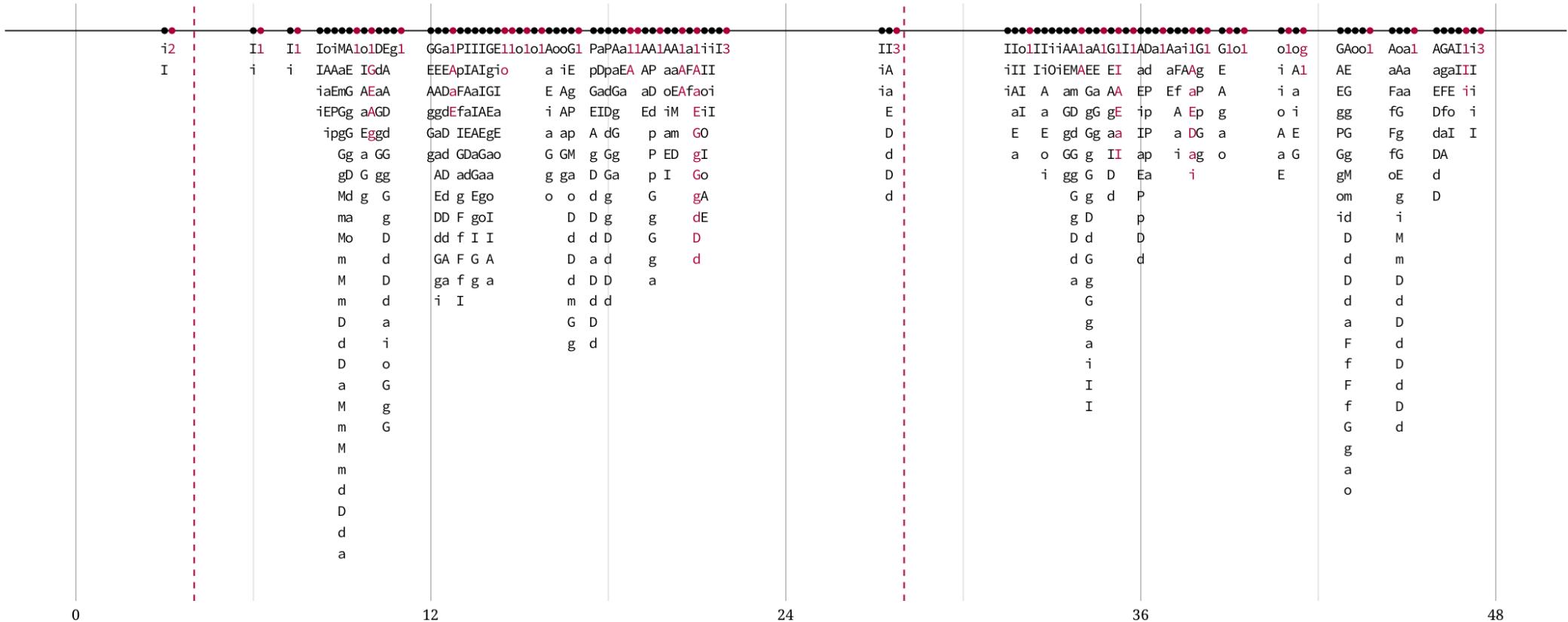
Event-String Timeline



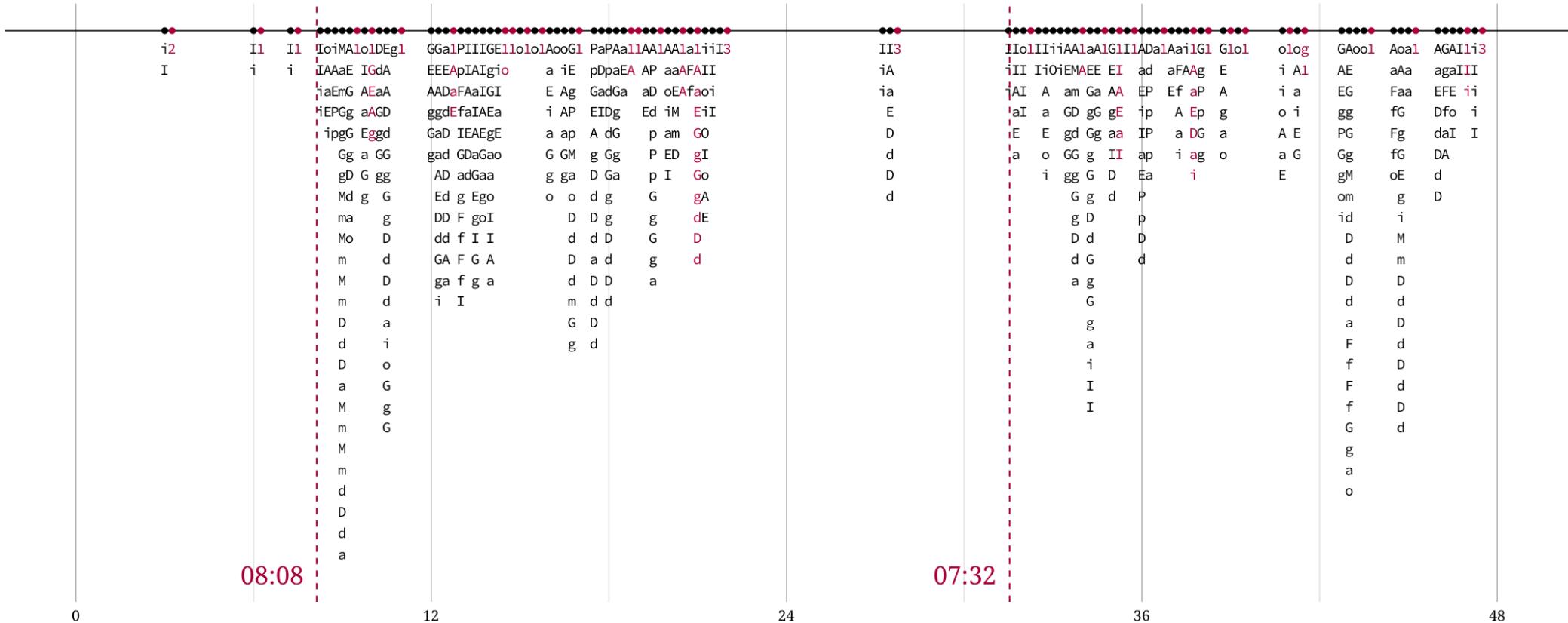
Day-Event Strings



Day-Event Strings



Day-Event Strings



Day-Event Strings

Day 1

_IIiioAaEiiAEPpMamGgGgMmMmMmDdDaMmMmdDdaAEGgGgDda1...

Day 2

_IiIiIAaEaoIII1IIIiAaEoii0iiA EaGgGgAMmDdGgGgDda1AaE...

Bags of n -grams from day-event-strings

Bigram

_I	ii	iI	II	IA	Aa	aE	Ea	ao	oI	II	II	I1	1I	II	II	Ii	iA	Aa	aE
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

Trigram

_Ii	iii	iII	III	IIA	IAa	AaE	aEa	Eao	aoI	oII	III	III	I1I	1II	III	III	IIi	IiA
iAa	AaE	aEo																

4-gram

_Iii	iiII	iIII	III	IIAa	IAaE	AaEa	aEao	EaoI	aoII	oIII	III1	III1	I1II	1III				
IIIi	IIiA	IiAa	iAaE	AaEo	aEoi													

5-gram

_Iiii	iiIIA	iIIIa	IIIaA	IIAaE	IAaEa	AaEao	aEaoI	EaoII	aoIII	oIII1	III1I	III1I						
IIII	1IIII	IIIiA	IIiAa	IiAaE	iAaEo	AaEoi	aEoi											

6-gram

_IiiII	iiIIAa	iIIIaE	IIIaEa	IIAaEa	IAaEao	AaEaoI	aEaoII	EaoIII	aoIII1	oIII1I	III1II							
IIIIII	I1IIII	1IIIIi	III1iA	IIIiAa	IIiAaE	IiAaEo	iAaEoi	AaEoi	aEoi									

Activity Profiles

Day 1 - Top n -grams

ngram	count	rank	freq
Dd	26	1	0.0152941
Gg	25	2	0.0147059
Aa	17	3	0.0100000
aE	14	4	0.0082353
dD	13	5	0.0076471
dDd	12	6	0.0070588
gG	12	7	0.0070588
GgG	11	8	0.0064706
AaE	10	9	0.0058824
DdD	10	10	0.0058824

Day 2 - Top n -grams

ngram	count	rank	freq
Gg	19	1	0.0152610
Dd	14	2	0.0112450
Aa	13	3	0.0104418
aE	10	4	0.0080321
AaE	9	5	0.0072289
II	9	6	0.0072289
dD	8	7	0.0064257
dDd	7	8	0.0056225
DdD	7	9	0.0056225
gG	7	10	0.0056225

Activity Profiles

Day 1 - Bottom n -grams

ngram	count	rank	freq
PpGgG	1	1211	0.0005882
PpGgGg	1	1212	0.0005882
PpMam	1	1213	0.0005882
PpMamG	1	1214	0.0005882
PpMao	1	1215	0.0005882
PpMaoD	1	1216	0.0005882
pPp	1	1217	0.0005882
pPpG	1	1218	0.0005882
pPpGg	1	1219	0.0005882
pPpGgG	1	1220	0.0005882

Day 2 - Bottom n -grams

ngram	count	rank	freq
PpGg1	1	903	0.0008032
PpGg1G	1	904	0.0008032
pPp	1	905	0.0008032
PpP	1	906	0.0008032
pPpa	1	907	0.0008032
pPpaa	1	908	0.0008032
pPpaa1	1	909	0.0008032
PpPp	1	910	0.0008032
PpPpa	1	911	0.0008032
PpPpaa	1	912	0.0008032

Activity Profiles

1. Transform sensor data into day-event-strings
2. Overall **Activity Profiles**
 - Bag, count and rank n -grams from collated observed day-event-strings
 - Compare activity profile (rank, freq) with unseen days
3. Daily or activity-level **Activity Profiles**
 - Bag, count and rank n -grams from individual day-event-strings
 - Compare activity profile across days

Similarity Measures

- Out of Place Ranking (Cavnar & Trenkle)

$$OOP = \sum_{s \in D} |r_P(s) - r_D(s)|$$

- Kullback-Leibler J -divergence

$$J(p, q) = \sum_i (p_i - q_i) \log(p_i/q_i)$$

- Distance measures directly on n -gram vectors

Cavnar and Trenkle (1994). doi:[10.1.1.53.9367](https://doi.org/10.1.1.53.9367)

Hornik et al. (2013). doi:[10.18637/jss.v052.i06](https://doi.org/10.18637/jss.v052.i06).

Sonnenburg et al. (2007). doi:[10.1.1.84.6387](https://doi.org/10.1.1.84.6387).

Activity Profile Demonstration

Given a collection of profiles for occupants and a day-event-string for a new day
can we correctly identify the occupant from their activity string?

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Setup

- 10 Houses
- 180 days
- Standardize sensor names

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Given a collection of profiles for occupants and a day-event-string for a new day
can we correctly identify the occupant from their activity string?

Setup

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Scenarios

- Add new house to "immature" group
- Add new house to "mature" group
- All houses evolve together

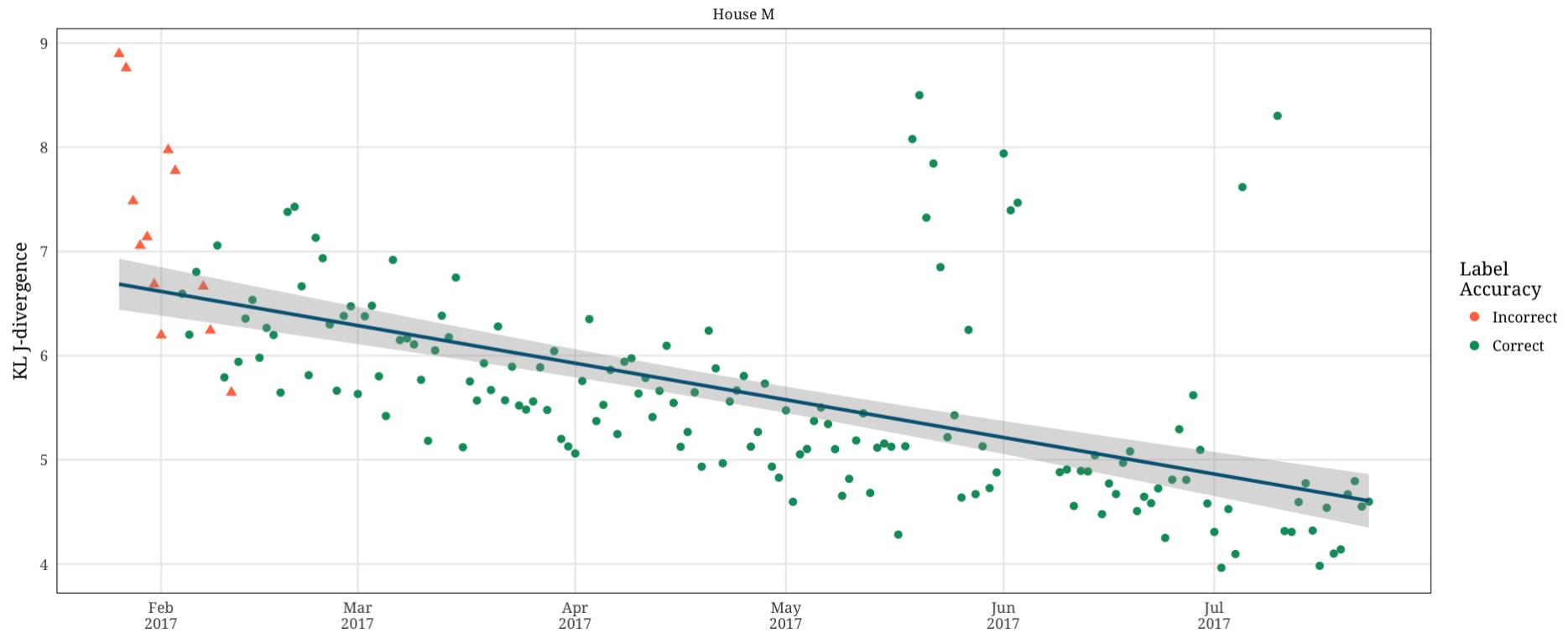
Results

House	30 days	140 days	Full Evolve
Average	98.45	96.09	99.02
B	100	99.42	100
C	98.32	95.53	100
D	98.88	97.21	100
E	100	100	100
G	98.29	96	98.29
H	96.65	91.62	100
I	97.69	95.95	95.95
J	99.44	97.75	100
L	98.08	94.23	95.51
M	97.06	92.94	100

Results

Self-Similarity Between Day-Event-String and Profile to date

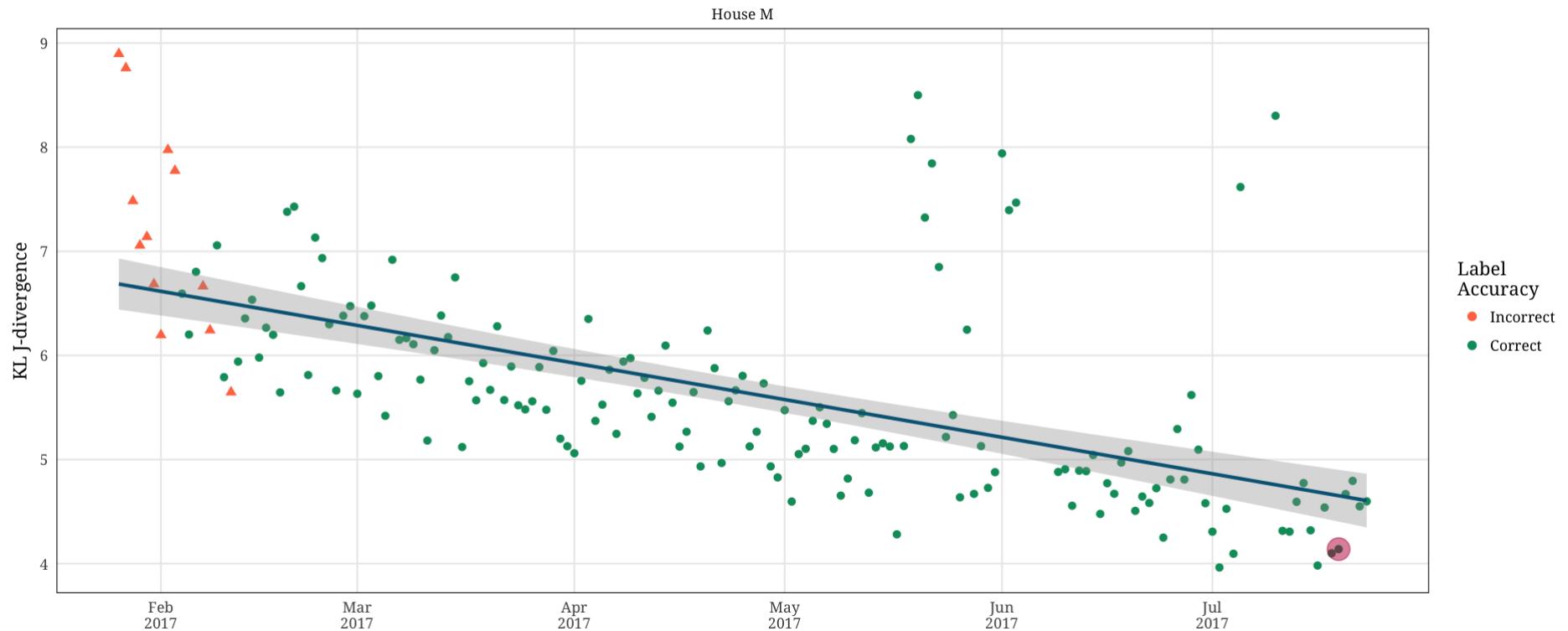
Other profiles trained on the first 140 days



Results

Self-Similarity Between Day-Event-String and Profile to date

Other profiles trained on the first 140 days



Dissertation

Dissertation

Research Questions

Can we make meaningful and timely observations of older adult's activities

- without needing labels
- without knowing floor plan or layout
- without an annotated training set
- and that works "out of the box"?

to create/enable

- Activity profiles
- Detection of changes in routine
- Early warning notification systems

Dissertation

Research Questions

Dissertation Outline

Create framework based on n -grams to naturally resolve the above problems, and demonstrate effectiveness with the following

1. Demonstrating day-event strings:

- Build individual profiles of each home
- How well can these profiles identify the originator of new activity data?
- Explore use of activity profiles to track occupant behavior change

2. Extending day-event strings:

- Use cluster analysis with the n -grams approach to identify and provide insight into anomalous days and events

Publications and Presentations

- **Ambient Intelligence Applications in Healthcare.**
Garrick Aden-Buie, A. Yalcin, C. VandeWeerd, A. Ngozichukwuka, J. Hammet, E. Yetisener, C. Radwan. *IIE Industrial and Systems Engineering Research Conferencee*. 2015
- **Comparison of Final Examination Formats in a Numerical Methods Course.**
Garrick Aden-Buie, A. Kaw, A. Yalcin. *International Journal of Engineering Education*. 2015
- **Rough Set Theory Based Prognostic Classification Models for Hospice Referral.**
E. Gil-Herrera and Garrick Aden-Buie, A. Yalcin, A. Tsalatsanis, L.E. Barnes, B. Djulbegovic. *BMC Medical Informatics and Decision Making*. 2015
- **Introduction to Engineering Design: Piloting design projects for the first year engineering experience.**
J. Gaines, B. Joseph, Garrick Aden-Buie. *Sixth Annual First Year Engineering Experience Conference*. 2014
- **Are multiple-choice questions suitable for a final examination in a STEM course?**
Garrick Aden-Buie, A. Kaw, A. Yalcin, R. Pendyala. *American Society for Engineering Education*, 2014.
- **Boosted Tree Ensembles for Predicting Postsurgical ICU Mortality.**
Garrick Aden-Buie, Y. Chen, R. Kayal, G. Romero, H. Yang. *INFORMS Annual Meeting*. 2013.

Thank you
Questions & Comments?

