Technology for Long-Term Care:
Scaling Activity Recognition to the Next Billion

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Intel Research

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Care and Machines

Long-Term Care Defined

Hands-on assistance with fundamental daily activities

"[Jean Gavrilles] was in good condition for her age, but she faced everything from advancing arthritis to what might be metastatic colon cancer…

The single most serious threat she faced was not the lung nodule or the back pain. It was falling. So [her geriatrician] referred Gavrilles to a podiatrist, whom he wanted her to visit once every four weeks, for better care of her feet."

From "The Way We Age Now", Atul Gawande, *The New Yorker*, May 2007

How We Care Today

elder

family

provider

case manager

High touch

High presence

High cost

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The Demographics Don't Favor Us...

% of population over age 60
- 30+ %
- 25-29%
- 20-24%
- 10-19%
- 0-9%

- 2 billion over 60 in 2050 (1 billion today) [UN]

- Caregivers per elder falling
  - 5:1 today, 3:1 2035 (USA), 2:1 Japan
  - 1 in 3 US adults does informal care annually [HHS]

... Nor Do the Economics
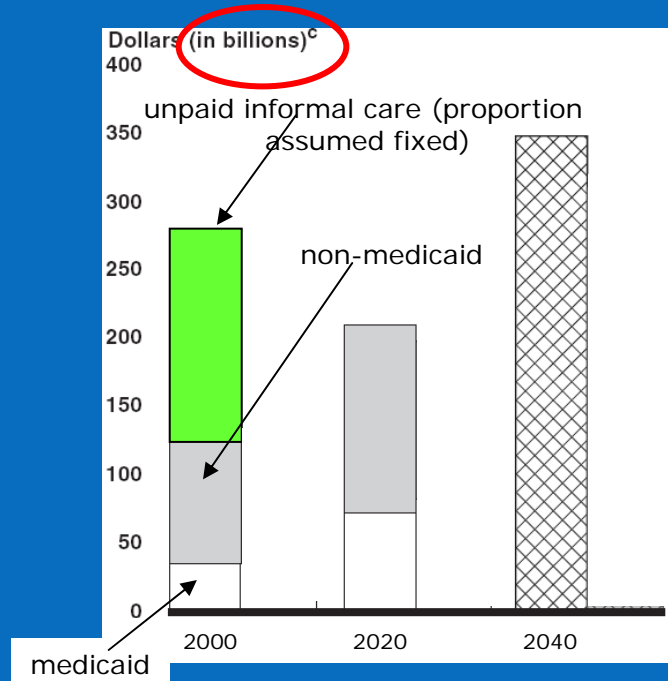
Total US Long-Term Care Expenditure
on Elderly (Medicaid + Private Pay)
(source: Congressional Budget Office, 2003; LaPlante *et al.*, 2002)

- Costs increase exponentially

- Budget will flatten

- Strategy
  - Reduce care needs
  - Support informal care
  - Reduce care cost

6   10/12/2007

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Machines are Not of Much Help

Keep an Eye Open

|	
Logging	What did they do?
Rating	How well?
Troubleshooting	What was wrong?
Trending	How have they changed?
Notification	Call me when they need me
Prompting	Walk them through it

Act

Mechanization	Automate structured tasks
Prosthetics	Help with physical functions
Assistance	Interact in unstructured tasks
Automation	Do these tasks autonomously

Connect emotionally

difficult
(for computer)

extremely difficult

Case Study:
Context-Aware Medication Prompting

(intel)
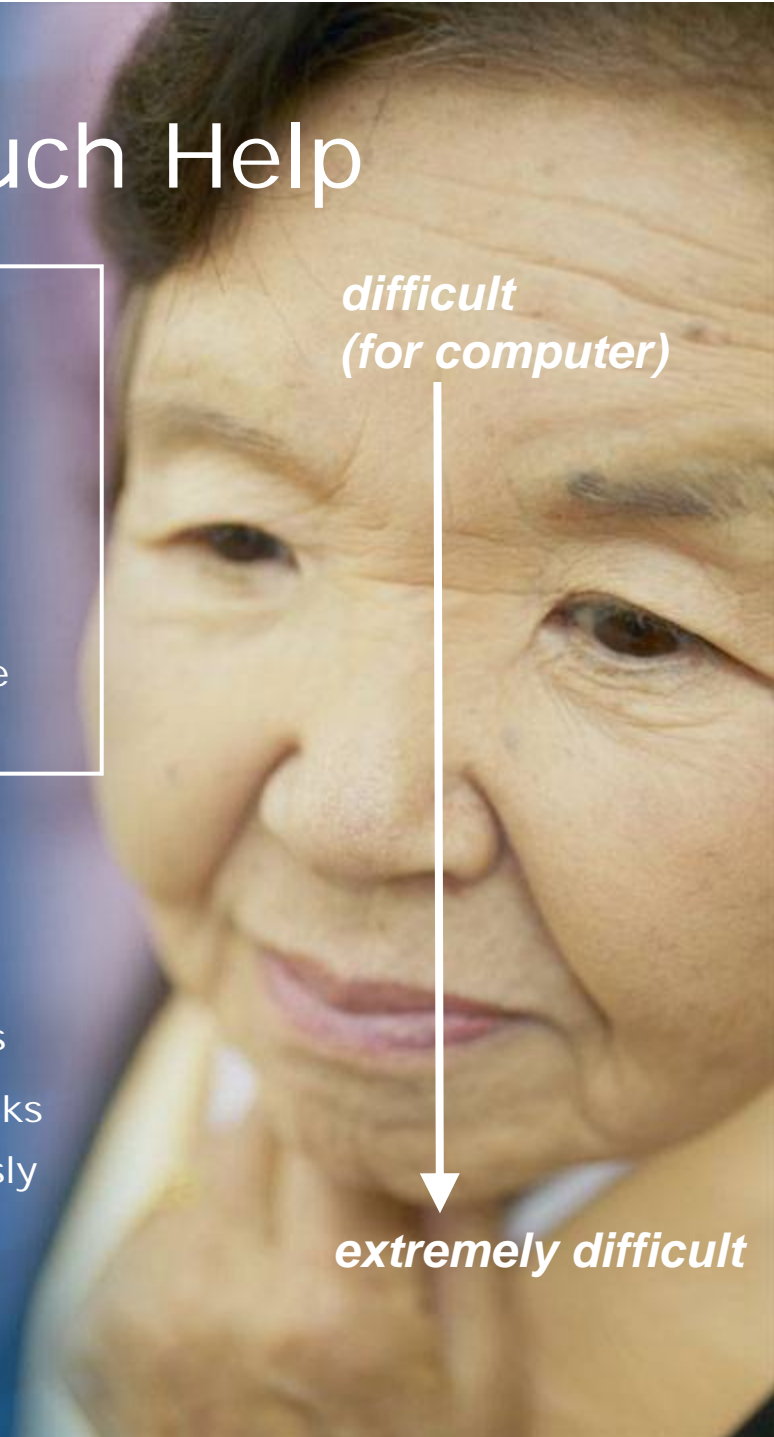
A Case Study

Context-Aware Medication Prompting

Hypothesis

Automated context-aware reminding can significantly improve medication adherence relative to state of the art reminding

Remind low-adherence elders *when appropriate*

– Leaving home at medication time

– Close to medications

– Not when sleeping or on the phone

Joint Oregon Health & Science University/Intel effort

– 10-12 health researchers, engineers, ethnographers

– Planned 1 yr study took roughly 2 years

The Results are Promising... Ubicomp 07

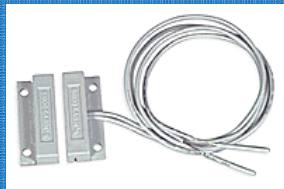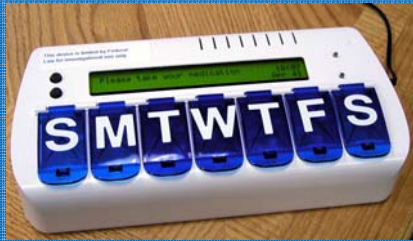| Participant	Baseline%	Time-Based%	Context-Aware%
HP05	33.3	69.1	54.2
HP52	75.8	70.2	84.9
M26	65.8	71.3	81.6
M32	47.7	77.0	93.1
M44	N/A	45.7	48.0
M45	58.3	46.1	81.8
avg.	56.2	63.2	73.9

>=6 week baseline, 3 week time-based, 3-week context-aware

Started with 14 elders, ended with 6
– All dropouts before baseline ended
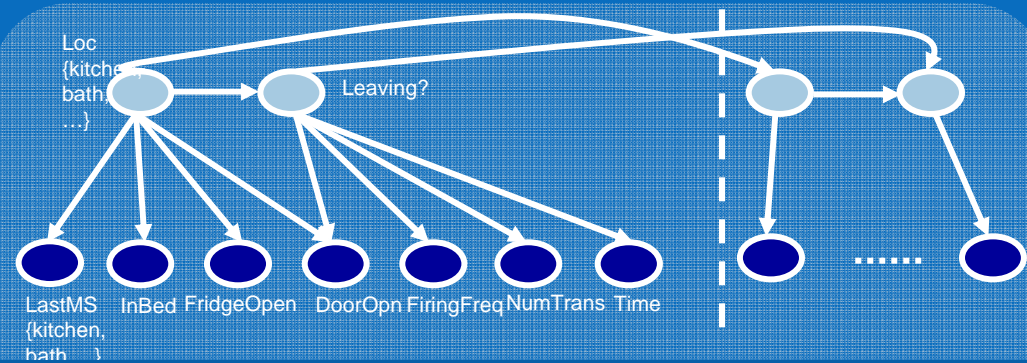– Unexpected extensions of baseline a major factor

...But at What Price?

Very hard to re-target or even improve solution

Loc {kitchen, bath, ...}

Leaving?

LastMS {kitchen, bath, ...} InBed FridgeOpen DoorOpn FiringFreq NumTrans Time

models encode "common sense", but hard for novices to specify, tough to re-use

integrating, modeling custom sensors

custom labeling rules

Location given by last motion sensor
– confused if you see other sensors e.g. door/bed

Leaving false by default, true if "door open" && at "door"
– confused if only one of "door open" or at "door"

Ask user if confused

resort to ad-hoc rules to speed labeling

The Target

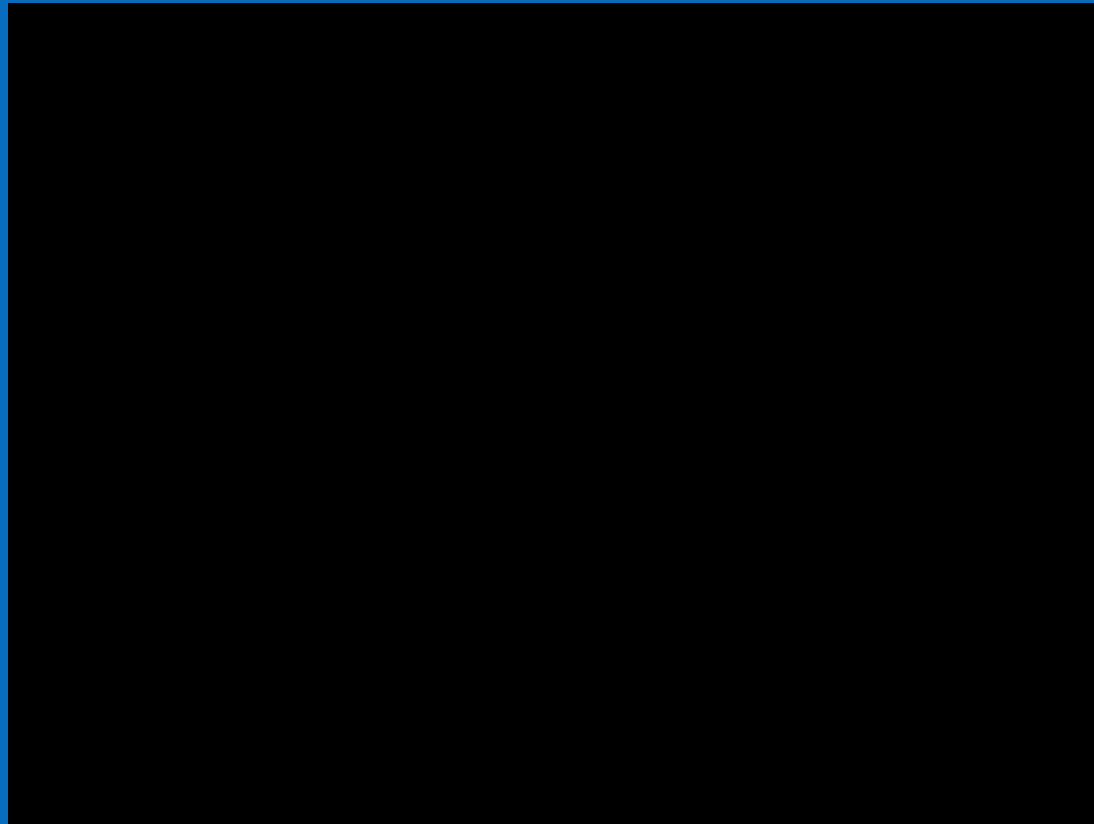| Activity Class	Rating (1-5)
Personal Appearance	
Oral Hygiene	
Toileting	
Washing up	
Appliance Use	
Use of Heating	
Care of clothes and linen	
Making a snack	
Making a drink	
Use of phone	
Leisure Activity	
Infant Care	
Medication Taking	
Housework	

shaving, brushing teeth, combing hair, flossing, gargling, applying make-up, bathing, using microwave, baking, blending, watching TV, doing laundry, mending, folding, putting away laundry, adjusting thermostat, making a sandwich, making a chocolate cake, making a martini, making a milkshake, getting a glass of water, phoning friends, phoning family, phoning caregivers, knitting, watching videos, going for a walk, walking the pet, putting grandson to bed, taking blood-pressure medication, taking vitamins, taking calcium, dusting, tidying, cleaning toilets, vacuuming, cleaning blinds, removing cobwebs, …
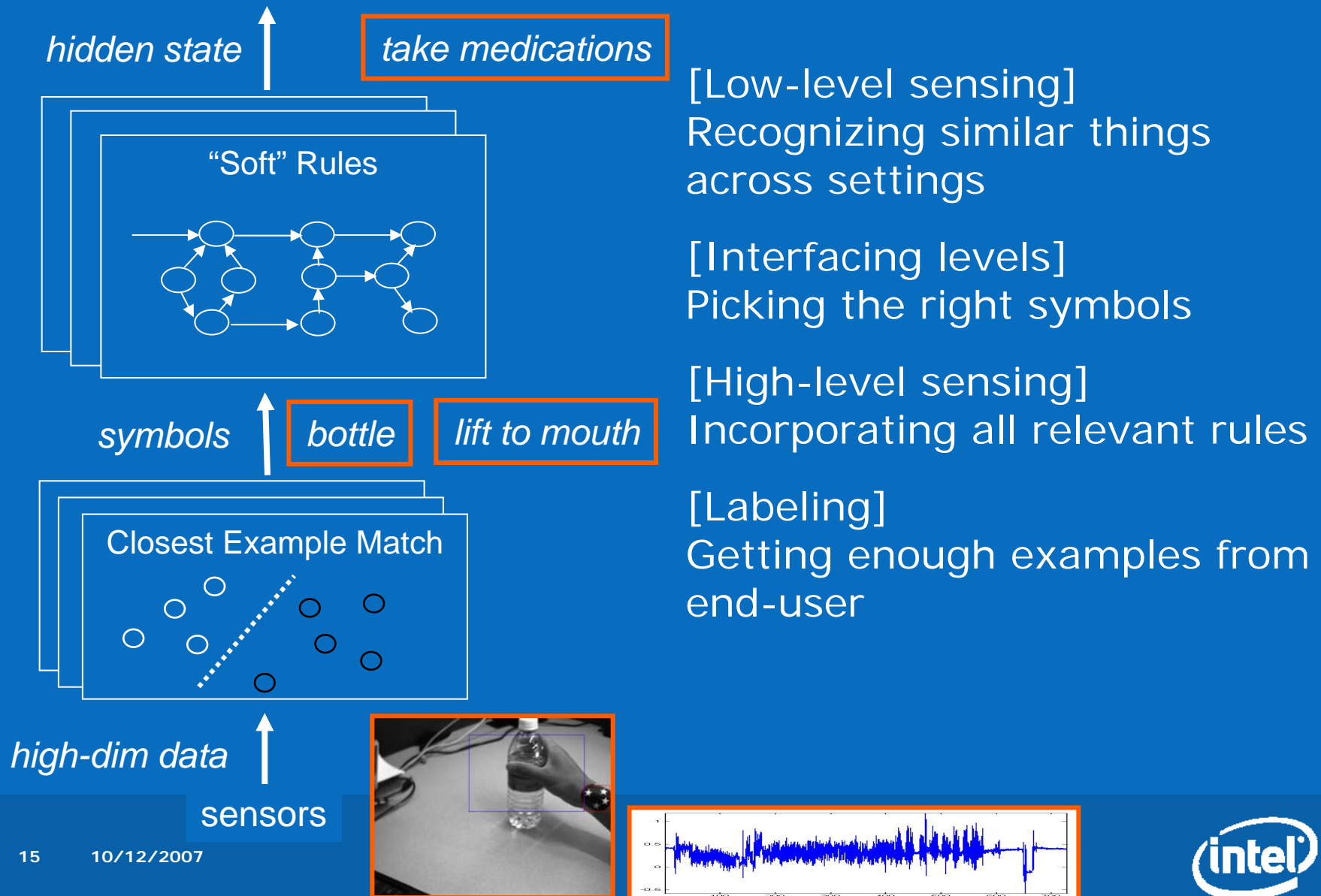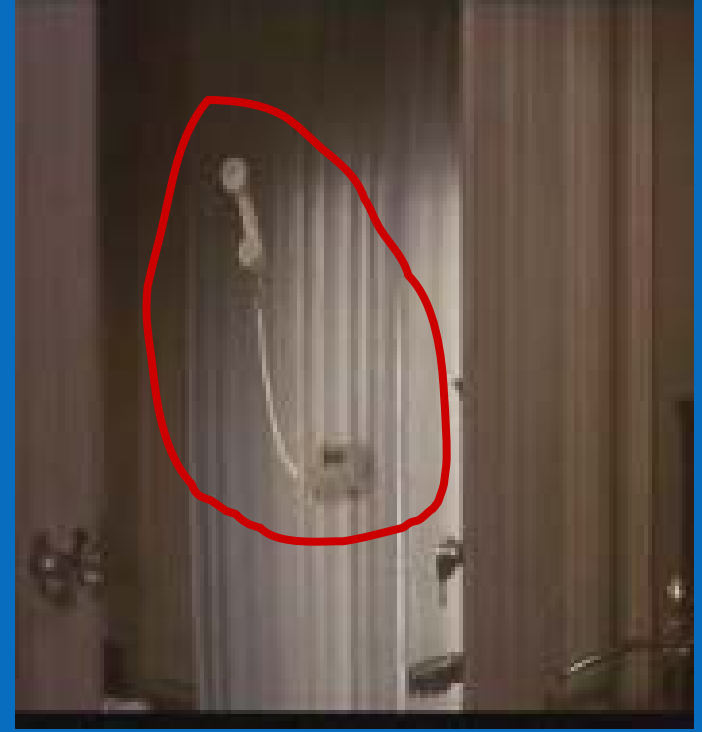
Scaling Human Activity Recognition

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Watching a Pot Boil

Bottlenecks in Human State Recognition

hidden state

take medications

symbols   bottle   lift to mouth

"Soft" Rules

Closest Example Match

high-dim data

sensors

[Low-level sensing]
Recognizing similar things
across settings

[Interfacing levels]
Picking the right symbols

[High-level sensing]
Incorporating all relevant rules

[Labeling]
Getting enough examples from
end-user

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What You Use Determines What You Do
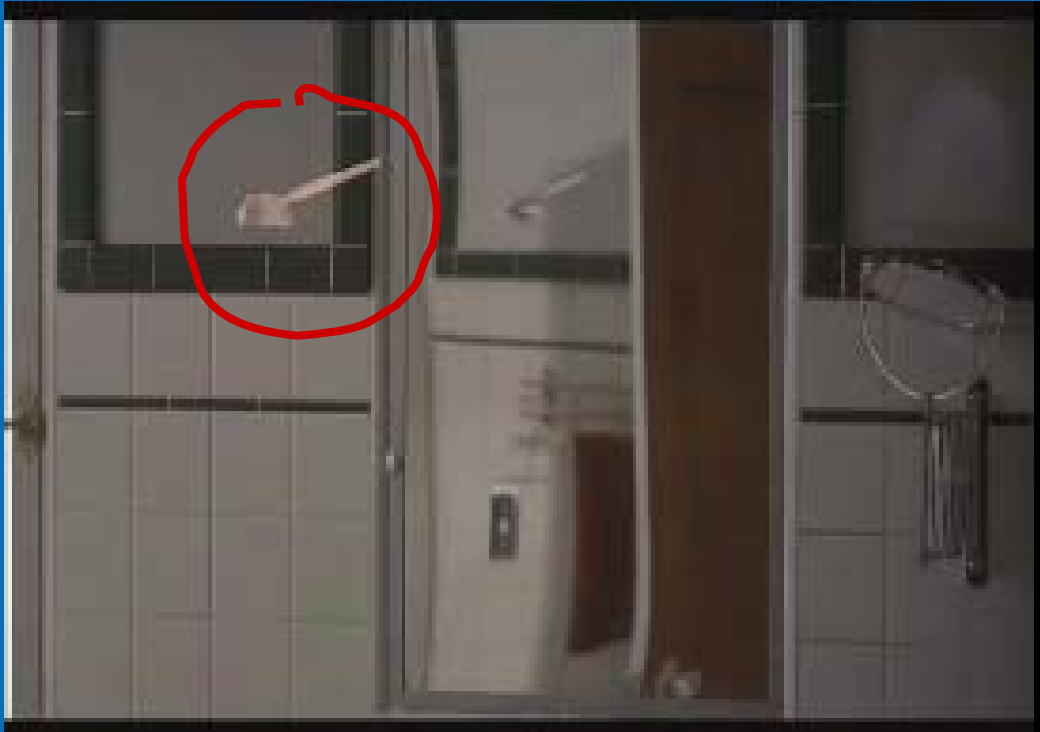
Activity Models Become Lists of Symbols

<Activity>

<Title>**making tea**</Title>

<StepList>

  <Step> <ObjectList> <Object name="**kettle**" /> <Object name="**water**" /> </ObjectList></Step>

  <Step> <ObjectList> <Object name="**cup**" /> <Object name="**teabag**" /> <Object name="**kettle**" /> </ObjectList></Step>

  <Step> <ObjectList> <Object name="**milk**" /> <Object name="**sugar**" /> <Object name="**cup**" /> <Object name="**spoon**" /> </ObjectList>

</Step>

</StepList> </Activity>

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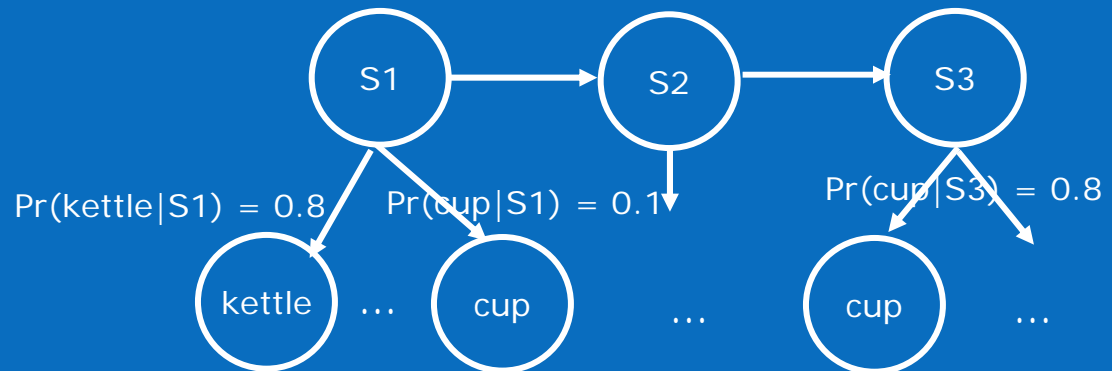
Detecting Object Use: Ultra-Dense Sensing

activities

Activity Recognition

objects used

Detect

e S

Segmen

data

RFID-based sensors

Who are you?
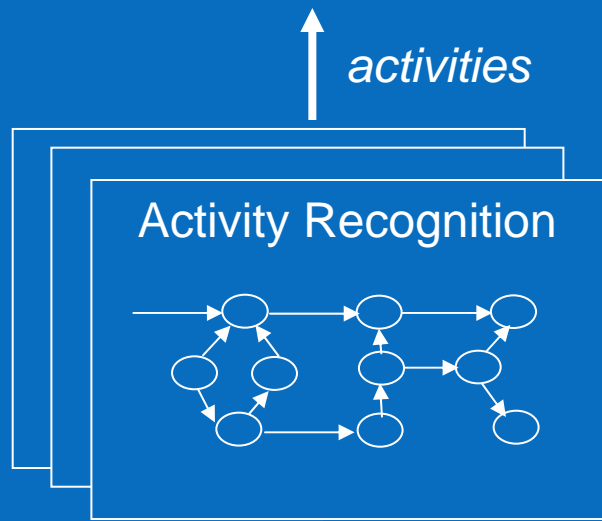
ID # 1287678087889343
[accel = (1.1,2.2,0.7)]

- 30 cents, tiny, no batteries

- 10s per sq ft possible

- insensitive to environment

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What Object-Use Sensing Buys You

IEEEPervasive04
ISWC05

Activity	Prior Work (Past 15 yrs, evaluated on any non-researcher)		HAR (3 mos prep, 14 subjects)
Personal Appearance			🟡
Oral Hygiene			🟡
Toileting	🔵		🟡
Washing up	🔵		🟡
Appliance Use			🟡
Use of Heating	🔵		🟡
Care of clothes and linen			🟡
Making a snack	🔵 🔵 🔵		🟡
Making a drink	🔵		🟡
Use of phone			🟡
Leisure Activity			🟡
Infant Care			🟡
Medication Taking	🔵		🟡
Housework			🟡

Legend

🟡 General solution

🔵 Point solution

70/90% average precision/recall

Caveat [Ubicomp07]
RFID often ineffective:
• Objects not tagged/ taggable
• Antenna gets detuned

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Case Study:
Technology for Long-Term Care

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TLC Study Goals

Show that activity monitoring technology can help maintain elders' independence by:

- Monitoring activities accurately

- Reducing perceived burden of care

- Satisfying elders, family and caregivers

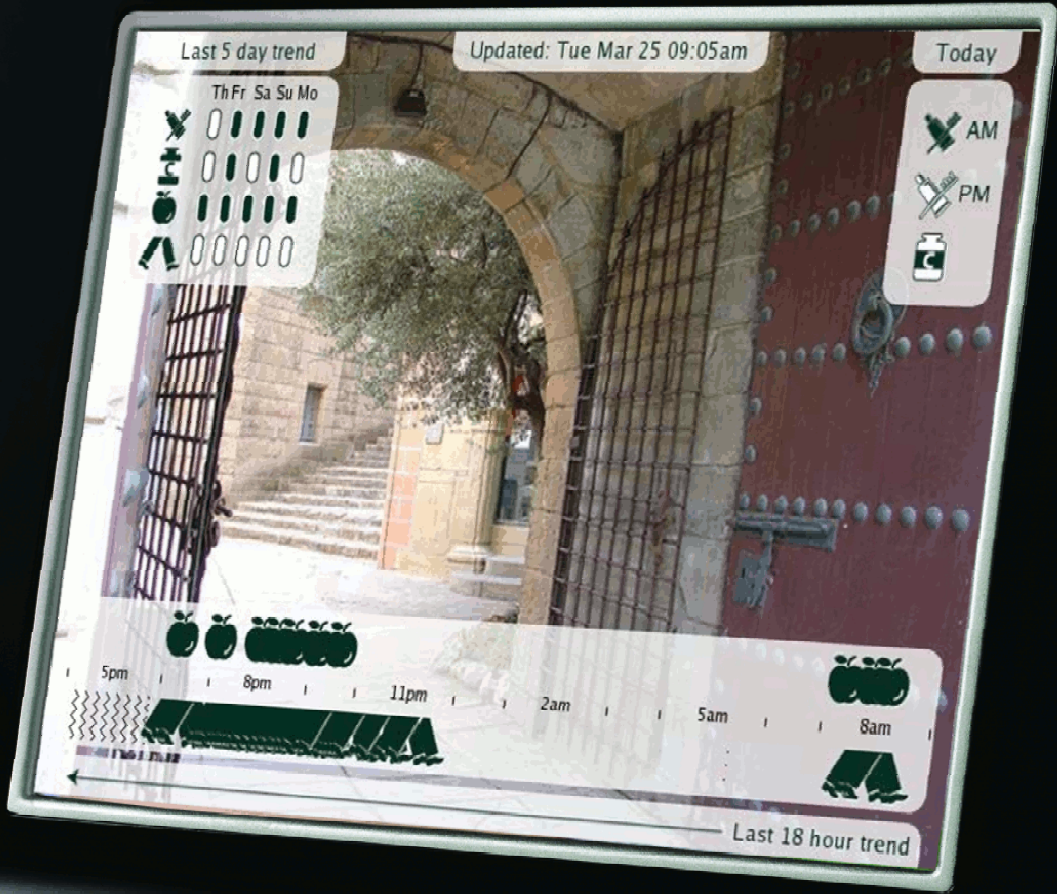- Triggering positive interactions between elders and caregivers

3-month, 20-elder + formal/informal caregiver, in-home deployment

Joint Intel, Veterans Administration, UW Health Sciences

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Dep

tracks 8 activities

Last 5 day trend
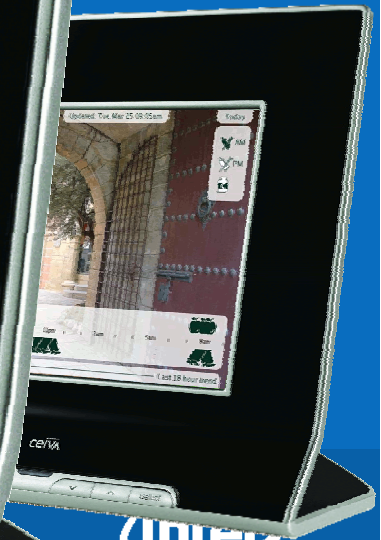Updated: Tue Mar 25 09:05am
Today

Th Fr Sa Su Mo

AM
PM

5pm 8pm 11pm 2am 5am 8am

Last 18 hour trend

08:17:37 to Tue
10:45:44 to Tue
5 12:39:10 to Tue

...ance

...em metrics

...isplay

...info, alerts

iBrac
detect
RFID t

sha
detec
vibr

...splays

TLC is Useful

elders

I think it's a marvelous thing… my sister will call me up say "I don't have any apples, why haven't you eaten?"

It reminds me--"hey, I didn't take my vitamins today." It gets me in a better habit. Sometimes I'll forget to brush my teeth at night after having a snack, but I can see that I didn't brush my teeth on the screen and then I'll go do it.

formal CGs

It's helpful… every shift, I have to sign off that he took his medications. When I sign his form I know for sure —before he would just tell me he took his meds **[note: TLC only monitors vitamin taking, not meds]**

He brushes his teeth more often now because I can keep track. That wasn't something I really did before.

informal CGs

It's like a huge night light lighting up the living room… before I'd call to check in on her. Now I can ask her why she hasn't eaten

Now, there's footprints all over it--so she wasn't sleeping last night. There's a break from about 3 to 4 in the morning. So, I won't bother her for awhile.

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Another Scaling Challenge

TLC installation overhead

Obj Inventory	60
Sensor ID	30
Sensor/Inf config	120
In-home PC/Net	20
In-home Sensors	30
backend setup	15

110 / 275 min

10x RFID

12x WSS

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The Bleeding Edge

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Object-Use Enables Common Sense Models

AAAI05
Pervasive06

Making Tea

activities

P = 0.9

Activity Recognition
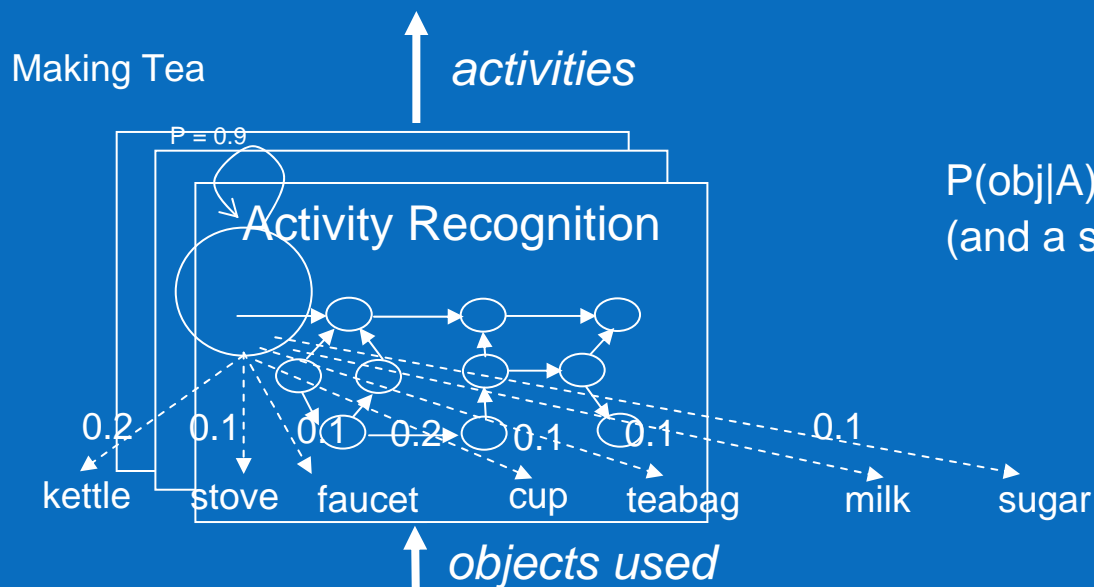
$$P(obj|A) = google(obj+A)/google(A)$$
(and a small bag of clean-up tricks)

0.2   0.1   0.1   0.2   0.1   0.1   0.1

kettle   stove   faucet   cup   teabag   milk   sugar

objects used
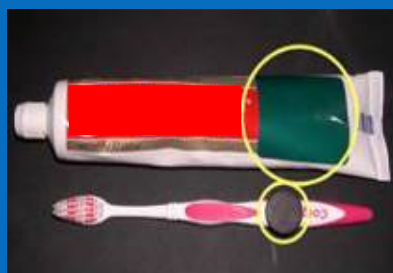
Mined models quite good:
~70% Precision/Recall **over 26 activities**

Can bootstrap semi-supervised learning: accuracy increases by up to 25% on unlabeled data

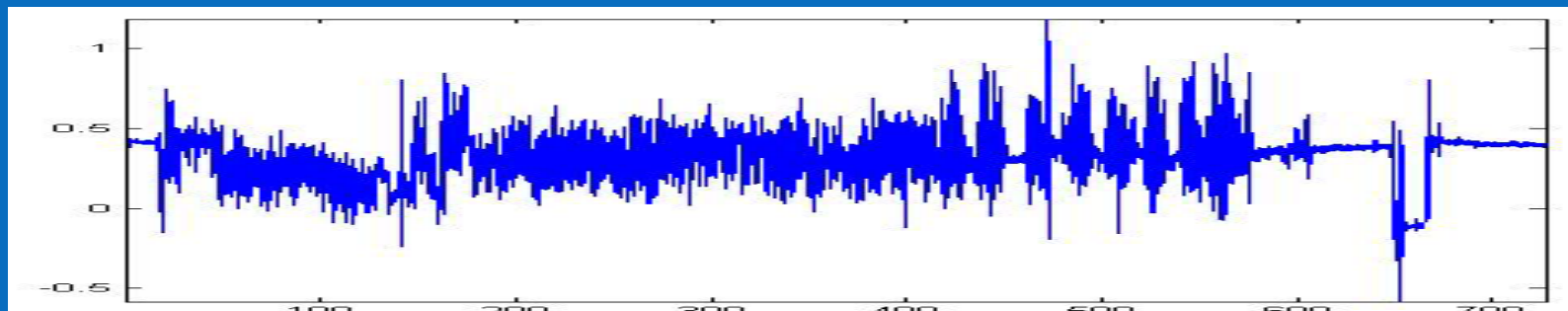RFID-based sensors

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Using Common Sense Databases

- Much effort spent collecting common sense
  - OpenMind Indoor Common Sense (OMICS), OpenMind, Cyc

- OMICS collected from internet users via fill-in-the blanks
  - "When people _____ they ___"

- Easily translated into logical formulas
  - personInState(X) => actionPerformed(Y)
  - actionPerformed(X) => objectUsed(y)

- Use web-scale mining to add quality numbers
  - personInState(hungry) =>**0.9** actionPerformed("eat")

- Convert weighted logic into giant Markov Random Field
  - 50,000 nodes/time slice, 30% of nodes are about object use

- 80%/40% precision/recall on **24 kinds of context** from RFID data
  - e.g., loactionInferred("bathroom"), actionPerformed("eat")

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Common Sense Assisted Sensor Labeling

object   bread   knife   knife   knife   jam jam   …   onion   knife   knife   knife   lettuce

activity   make jam sandwich   make salad

action   spread   spread   spread   chop   chop   chop
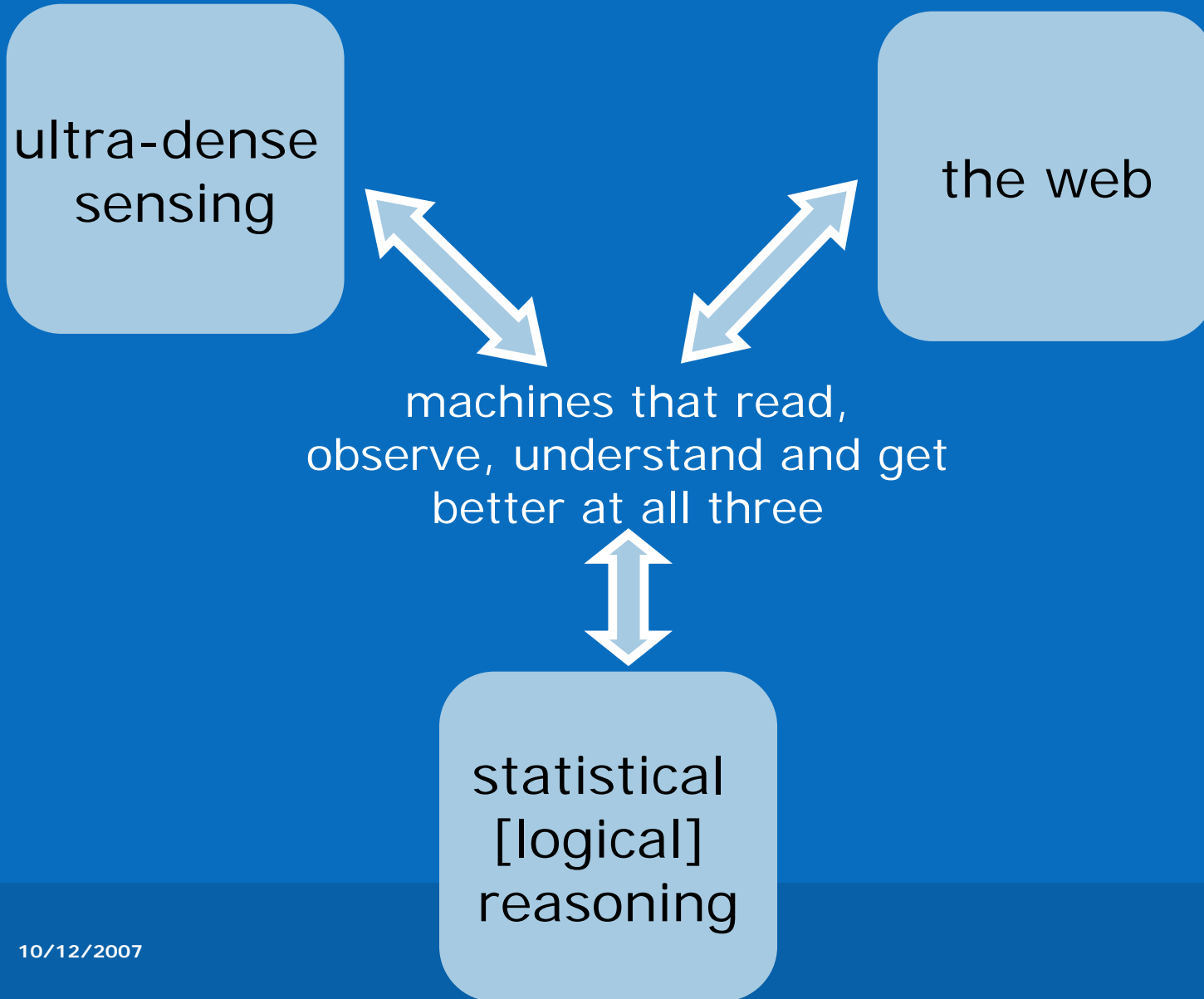slice   slice   slice   slice   slice   slice
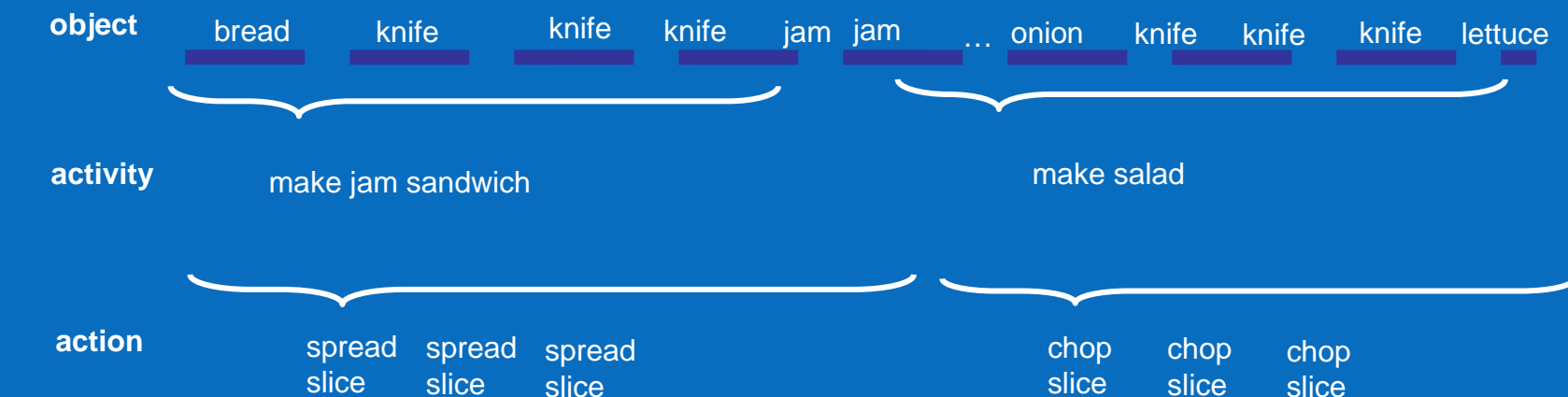
accelerometer

- Easily get to 50-80% Precision/Recall [IJCAI07]
- Trick works for vision too [ICCV07]

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The Self-Sustaining Reaction...

ultra-dense sensing

the web

machines that read, observe, understand and get better at all three

statistical [logical] reasoning

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The Road Ahead

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Intel Everyday Sensing & Perception Initiative

Mainstreaming is the ultimate scaling trick

Understand 90% of your day with90% accuracy

Location & Navigation
Location-based security
Finding lost & hidden objects
Fitness tracking
Auto trip report
Smart scrap booking
Virtual tour guide
Home automation
Context-aware Interruptions
home security monitoring
Real time energy awareness
Smart appliances
Entertainment integration
In-situ recommender systems
"Visual Google"
Personal Health Monitoring
Smart shopping assistant
Social networking
Context-aware filtering
Pre-destination / route prediction

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Affecting Clinical Care

Technology can make behavioral monitoring a valuable clinical tool, similar to physiological monitoring

Clinical Behavioral Metrics Project:

- Sensor-based data can provide metrics of wellness significantly better correlated with outcomes than current standards

Generalized Adherence Monitoring:

- Delivering regimen adherence information to patients and care givers will improve compliance rates and outcomes

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Follow the Money

Public policy can affect perceived value of technology

Problem: Fixed-time, fixed-cost reimbursement hides tech benefits

- E1: *It hasn't changed anything she does for me, she still does all of the same things.*

- E2: *She does everything like she always did. I've been doing everything by myself before this came up. It's no different now.*

- FCG1: *He brushes his teeth more often now because I can keep track. That wasn't something I really did before.*

- FCG2: *Every shift I have to sign off that he took his medications.*

Proposal: Need-based care

- Care worker visits less if elder performs more tasks
  - fewer visit == lower up-front cost

- Elder receives incentives to self-perform task

- Sensors provide objective measure of need

- Partner with org controlling service plan e.g. VA to validate?

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The Pieces of the Puzzle

In the story of Jean Gavrilles and her geriatrician, there's a lesson about frailty. [Aging] can occur in two ways. One is early and precipitately, with an old age of enfeeblement and dependence, sustained primarily by nursing homes and hospitals. The other way is more gradual, preserving, for as long as possible, your ability to control your own life.

From "The Way We Age Now", Atul Gawande, *The New Yorker*, May 2007

Thank You

Collaborators:

B. Gutmann, A. Mani, D. Patterson, W. Pentney, A.-M. Popescu, E.-M. Tapia, S. Wang, D. Wyatt, D. Wilson, B. Ziebart

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