Life Patterns
structure from wearable sensors

by
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Thesis Readers: Prof. Trevor Darrell
Prof. Joseph Paradiso
The Question: Can we computationally structure a sensor record of an individual’s day-to-day life?

sensor record - “dumb” measurements via sensors

structure - similarity measure, perplexity, prediction, classification

The Applications:
memory prosthesis
automatic diary
the frame problem
“the past explains”
context-aware agents
Vannevar Bush - memex (1945)

Wearable Sensing
- Steve Mann - wearable cameras (1997)
- Thad Starner - Patrol system (1999)
- Farringdon et. al. - sensory badges & jackets (1999)

Context-Awareness
- Brad Rhodes - Remembrance Agent (2000)
- Lamming & Flynn - “Forget-me-not” (1994)

Robotics & AI
- Grimson et. al. - long-time monitoring of a site (1998)
- Jogan & Leonardis - localization via panoramic views
Talk Outline

Why?
Data Collection
Similarity Measure
Life's Perplexity
Situation Classification

Prologue
The “I Sensed” Data Set

Mr. Kawara On [1933- ]

Date paintings
The “I Sensed” Data Set

Mr. Kawara On [1933- ]

The “I Got Up” Series

I Went
I Met
I Am Alive
I Read ...
The “I Sensed” Data Set

Data Collection Wearable
The “I Sensed” Data Set

Data Collection Wearable

- Gyros
- Rear camera
- Interface board
- P III 500MHz Cell Computer & 10GB HDD
- Sony Infolithium Batteries
- Rear camera lens
- Buttons
- Front camera
- Microphone

Demo available
Key Properties: low resolution, wide field-of-view

compared to humans:
- 100,000 times fewer photoreceptors
- 360-deg field of view
- 800 eye units, each having 8 photoreceptors
The Similarity Measure

Peripheral vs. Attentive

Peripheral sensing is robust to small changes in the environment.

Direct image matching without correspondence is potentially useful!
The Similarity Measure

Front View Eigenvectors

Rear View Eigenvectors

Trained on 32x24 pixel images over 30 days of video.

Bell & Sejnowski - PCA of natural scenes yields Fourier basis
ICA of natural scenes yields localized edge filters
- Compression without loss of detail is difficult.
- We use the top 100 eigenimages for the remaining experiments.
- The result is a 200-dimensional feature vector per frame
- To compare frames, we use the L-1 norm.
The Similarity Measure

Sequence Similarity

How do we compare a pair of frames sequences?
The Similarity Measure

Sequence Similarity

Match one sequence to the other and accumulate frame-by-frame similarities.
A sequence of frames becomes a Hidden Markov Model.

the transitions...
The Similarity Measure

\[ \alpha \text{-transitions} \]
\[ \beta \text{-transitions} \]

Equal probability

Low constant probability

**Alignment Model**
The Viterbi Algorithm produces the best possible alignment.
The Similarity Measure

An Example: walking to lab

these are very similar events...

3000 frames thus 3000 states (computationally heavy!)
The Similarity Measure

Another Example: leaving class

clearly at times, dissimilar at others
The Similarity Measure

Remove Redundancy via Image Similarity

Before
1 day = 200,000 images

After
1 day = 3,000 images

demo available
RLE at 15% allows alignment of a pair of days!
The Similarity Measure

Alignment of a day

The finer detail in the morning...

demo available
Problem:
- A pair of days typically only align sensibly for a few situations.

Solution:
- Keep adding more sequences to the alignment HMM.

Aligning 1 day to 30 days:
- Build similarity matrix of 30 days at 5 minute resolution.
- Build alignment HMM from each 5 minute chunk in 29 days.
- Align remaining day to the 29 days using the HMM.
- repeat 30 times...
## The Similarity Measure

### Alignment of a month

<table>
<thead>
<tr>
<th>Source Day</th>
<th>Destination Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Wed 05/09</td>
<td>2 Thu 05/10</td>
</tr>
<tr>
<td>2 Thu 05/10</td>
<td>3 Thu 05/10</td>
</tr>
<tr>
<td>3 Thu 05/10</td>
<td>4 Fri 05/11</td>
</tr>
<tr>
<td>4 Fri 05/11</td>
<td>5 Sat 05/12</td>
</tr>
<tr>
<td>5 Sat 05/12</td>
<td>6 Sun 05/13</td>
</tr>
<tr>
<td>6 Sun 05/13</td>
<td>7 Mon 05/14</td>
</tr>
<tr>
<td>7 Mon 05/14</td>
<td>8 Tue 05/15</td>
</tr>
<tr>
<td>8 Tue 05/15</td>
<td>9 Wed 05/16</td>
</tr>
<tr>
<td>9 Wed 05/16</td>
<td>10 Thu 05/17</td>
</tr>
<tr>
<td>10 Thu 05/17</td>
<td>11 Fri 05/18</td>
</tr>
<tr>
<td>11 Fri 05/18</td>
<td>12 Sat 05/19</td>
</tr>
<tr>
<td>12 Sat 05/19</td>
<td>13 Sun 05/20</td>
</tr>
<tr>
<td>13 Sun 05/20</td>
<td>14 Mon 05/21</td>
</tr>
<tr>
<td>14 Mon 05/21</td>
<td>15 Tue 05/22</td>
</tr>
<tr>
<td>15 Tue 05/22</td>
<td>16 Wed 05/23</td>
</tr>
<tr>
<td>16 Wed 05/23</td>
<td>17 Sun 05/27</td>
</tr>
<tr>
<td>17 Sun 05/27</td>
<td>18 Mon 05/28</td>
</tr>
<tr>
<td>18 Mon 05/28</td>
<td>19 Tue 05/29</td>
</tr>
<tr>
<td>19 Tue 05/29</td>
<td>20 Wed 05/30</td>
</tr>
<tr>
<td>20 Wed 05/30</td>
<td>21 Thu 05/31</td>
</tr>
<tr>
<td>21 Thu 05/31</td>
<td>22 Fri 06/07</td>
</tr>
<tr>
<td>22 Fri 06/07</td>
<td>23 Sat 06/09</td>
</tr>
<tr>
<td>23 Sat 06/09</td>
<td>24 Sun 06/10</td>
</tr>
<tr>
<td>24 Sun 06/10</td>
<td>25 Mon 06/11</td>
</tr>
<tr>
<td>25 Mon 06/11</td>
<td>26 Tue 06/12</td>
</tr>
<tr>
<td>26 Tue 06/12</td>
<td>27 Wed 06/13</td>
</tr>
<tr>
<td>27 Wed 06/13</td>
<td>28 Fri 06/15</td>
</tr>
<tr>
<td>28 Fri 06/15</td>
<td>29 Sat 06/16</td>
</tr>
<tr>
<td>29 Sat 06/16</td>
<td>30 Sun 06/18</td>
</tr>
<tr>
<td>30 Sun 06/18</td>
<td>31 Mon 06/19</td>
</tr>
<tr>
<td>31 Mon 06/19</td>
<td>32 Tue 06/19</td>
</tr>
<tr>
<td>32 Tue 06/19</td>
<td>33 Wed 06/20</td>
</tr>
</tbody>
</table>

### Simultaneous Alignment of 30 Days

The diagram shows the similarity measurements for a month, with days represented on the x-axis and y-axis. The color gradient indicates the level of similarity, with yellow representing high similarity and blue representing low similarity.
Each moment can be aligned to any moment in 29 days.

we will use this later...
“When you come to a fork in the road, take it.”

- Where are the decision points? (i.e. what are the nodes)
- What is the perplexity each time a decision is made?
- How consistent is the decision?
β-transitions denote moments of divergence from past behavior.

Score each β-transition by its size in time.
Sweeping a threshold yields a hierarchy of scene segmentations. 30 days = ~1000 scenes.

To get scenes cluster using alignment as the similarity measure.
Degree of redundancy is independent of the # of nodes.
Life’s Perplexity

30 Scene Clusters

Accuracy is independent of perplexity!
situation = location + activity
<table>
<thead>
<tr>
<th>Situation</th>
<th>Location/Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>home</td>
<td>apartment</td>
</tr>
<tr>
<td>neighborhood</td>
<td>Beacon St., Mass. Ave. (Boston-side)</td>
</tr>
<tr>
<td>bridge</td>
<td>Harvard Bridge, Longfellow Bridge</td>
</tr>
<tr>
<td>street</td>
<td>Kendall Sq., Boston Downtown, Main St., Memorial Dr., and more</td>
</tr>
<tr>
<td>hallway</td>
<td>Infinite Corridor and more</td>
</tr>
<tr>
<td>campus</td>
<td>inside &amp; outside of bldg. 56, 66, 7, 10, and more</td>
</tr>
<tr>
<td>at work</td>
<td>anything in the Media Lab</td>
</tr>
<tr>
<td>elevator</td>
<td>any elevator</td>
</tr>
<tr>
<td>stairs</td>
<td>any stairs</td>
</tr>
<tr>
<td>office</td>
<td>my office at lab</td>
</tr>
<tr>
<td>lab</td>
<td>the area outside of my office</td>
</tr>
<tr>
<td>meeting</td>
<td>any meeting</td>
</tr>
<tr>
<td>kitchen</td>
<td>kitchen (at home and lab)</td>
</tr>
<tr>
<td>bathroom</td>
<td>any bathroom</td>
</tr>
<tr>
<td>gym</td>
<td>Dupont</td>
</tr>
<tr>
<td>vehicle</td>
<td>taxi, subway, bus</td>
</tr>
<tr>
<td>store</td>
<td>any store</td>
</tr>
<tr>
<td>restaurant</td>
<td>any restaurant</td>
</tr>
<tr>
<td>class</td>
<td>any class</td>
</tr>
</tbody>
</table>

* Every 5 minute interval over 20 days was labeled with its situation(s).
Context-Free Classification of Situation

Total:
rank-1 = 89%
rank-2 = 95%
Context-Free Classification of Situation (Far vs. Near)

<table>
<thead>
<tr>
<th>Location</th>
<th>Percentage</th>
<th>chance</th>
<th>far</th>
<th>near</th>
</tr>
</thead>
<tbody>
<tr>
<td>home</td>
<td>0.9</td>
<td>0.0</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>neighborhood</td>
<td>0.9</td>
<td>0.0</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>bridge</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>street</td>
<td>0.7</td>
<td>0.3</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>hallway</td>
<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>campus</td>
<td>0.7</td>
<td>0.3</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>at work</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>elevator</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>stairs</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>office</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>lab</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>meeting</td>
<td>0.7</td>
<td>0.3</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>kitchen</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>bathroom</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>gym</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>vehicle</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>store</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>restaurant</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>class</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

Total:
far = 72%
near = 95%
Classification of Situation with Context

- **Total:**
  - rank-1 = 94%
  - rank-2 = 97%
Hybrid Classification of Situation

- Home: 0.9
- Neighborhood: 0.8
- Bridge: 0.7
- Street: 0.6
- Hallway: 0.5
- Campus: 0.4
- At work: 0.3
- Elevator: 0.2
- Stairs: 0.1
- Office: 0
- Lab: 0
- Meeting: 0
- Kitchen: 0
- Bathroom: 0
- Gym: 0
- Vehicle: 0
- Store: 0
- Restaurant: 0
- Class: 0
- Total: 0.9

Percentage

Total: rank-1 = 97%
What have we shown?

- Capturing complete records of an individual’s day-to-day life is practical.
- The capabilities of peripheral and insect-like perception.
- Simple models can capture even the complex structure of human behavior.
- How to compare moments of an individual’s life at multiple time-scales.
- That day-to-day behavior is redundant at multiple scales.
- How to classify situations.
I am indebted to...

Sandy, my patient advisor
Joe and Trevor, my patient thesis committee
Sumit, Tanzeem and Vikram, my officemates
All the Vismodders: Karen, Rich, Nathan, Steve, Liz, Tony, and many more.

All of my friends in the gymnastics team, the breakin’ crew Imobilare, and Japanese class.

I dedicate this work to my little brother, Peter.
Life Patterns
structure from wearable sensors

The End