Cognitive Science and Data Science

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1 Cognitive Science and Data Science
   - Introduction
   - Smart Phone Data
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2 Case Studies
   - Modeling Human Language Processing
   - Object Detection
The aim of cognitive science is to figure out how the mind works.
Cognitive scientists do this by studying a range of cognitive processes:

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- language;

```plaintext
S
   /\   /
  NP VP
  /\   /
 N' V'
 /\   /
AdjP AdjP N' V' AdvP
 /\   /
Adj' Adj' N' V' Adv'
 /\   /
Adj Adj' N  V  Adv
 /\   /
Colorless Adj ideas furiously
 /\   /
green
```
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- learning and inference;

\[ y_i \sim \text{Normal}(\mu_i, \sigma) \]

\[ \mu_i = \alpha + \beta x_i \]
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Building models of cognitive processes is a central to cognitive science.
Data and Models

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If we want to find out if high-frequency words are recognized faster than low-frequency words, we run a lexical decision experiment and model it:

(图示实验结果和模拟结果，图中灰色表示大邻域，红色表示小邻域)

(gray: large neighborhood, red: small neighborhood)
Beyond Experimental Data

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Data from controlled experiments is great for forming theories and building models. But we also want predict naturalistic behavior. So we need to test our models on:

- data from experiments of thousands of people (crowdsourcing);
- large real-time data streams (eye-tracking, brain imaging);
- gigabytes of text, images, videos, tweets (large corpora, web data).

This is where data science comes in.
Let’s collect lexical decision data from thousands of participants, for dozens of languages (Dufau et al. 2011):

Could add geolocation, sensor data, social media data profiles . . .
Let’s study how humans do word recognition in real text:

An eye-tracker generates large amounts of data: 2000 frames per second.
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Buck did not read the newspapers, or he would have known that trouble was brewing, not alone for himself, but for every tide-water dog, strong of muscle and with warm, long hair, from Puget Sound to San Diego. Because men, groping in the Arctic darkness, had found a yellow metal, and because steamship and transportation companies were booming the find, thousands of men were rushing into the Northland. These men wanted dogs, and the dogs they wanted were heavy dogs, with strong muscles by which to toil, and furry coats to protect them from the frost.

Buck lived at a big house in the sun-kissed Santa Clara Valley. Judge Miller’s place, it was called. It stood back from the road, half hidden among the trees, through which glimpses could be caught of the wide cool veranda that ran around its four sides.
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Case Studies
Eye-tracking data provides evidence about human language processing:

- words are fixated longer if they are infrequent, long, or ambiguous;
- syntactic ambiguity leads to re-reading (reverse saccades);
- fixation duration also varies with semantic plausibility, sentence and discourse context, reading task.
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We can use such evidence to build cognitive models that simulate human language processing.
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PLTAG: incremental parsing and semantic role labeling (Konstas et al. 2014):

1. NP → ⟨{A0,A1,A2,A3},Banks,nil⟩
2. VP → ⟨AM-MOD,will,nil⟩
PLTAG: incremental parsing and semantic role labeling (Konstas et al. 2014):

3. $\text{NP} \rightarrow \langle \{A_0,A_3\}, \text{Banks}, \text{take} \rangle$
   $\text{VP} \rightarrow \langle \text{AM-MOD}, \text{will}, \text{take} \rangle$

4. $\text{NP} \rightarrow \langle A_1, \text{measures}, \text{take} \rangle$
Dundee Eye-tracking Corpus

Evaluate PLTAG model against a large, naturalistic dataset:

- 51,502 words of English newspaper text;
- read by 10 native speakers while being eye-tracked;
- test how well the model predicts first-pass reading times;
- control for low-level factors such as word length and word frequency.
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Linear mixed effects regression shows:

- PLTAG probability significant predictor of reading time;
- explains variance not accounted from by n-gram language model;
- outperforms Surprisal (competing model).
Object Detection

We can use eye-tracking data for a classic computer vision task: object class detection.

Object detectors are trained on images that are manually annotated with bounding boxes around the objects.
Alternative: infer bounding boxes from eye-tracking data (Papadopoulos et al. 2014):

- much faster: 1 s per image vs. 26 s for bounding box drawing;
- no need for trained annotators, guidelines, etc.
From Fixations to Bounding Boxes

$R_{bb+fix}$

$R_{fix}$

Features

Training a superpixel classifier

Initial object segmentation

Segmentation Refinement
From Fixations to Bounding Boxes

Evaluation using CorLoc (intersection over union $> 0.5$):

- whole image: 33.2
- objectness: 35.0
- all fixations: 4.0
- regression: 35.6
- position+time+appearance: 46.5
- position+time+appearance+objectness: 49.6
