# Reasoning with Compositional Concepts

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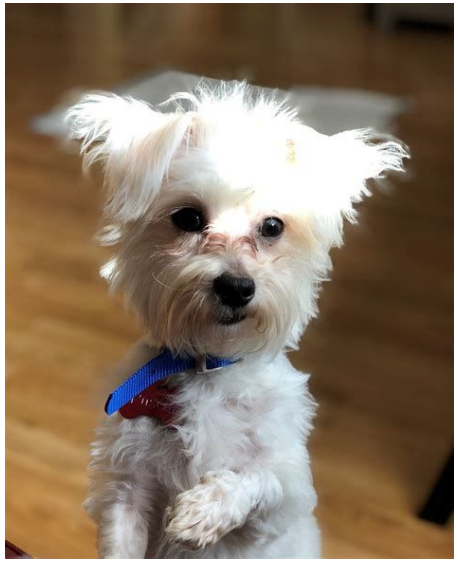
# Think of dogs



# What is a dog?

**A combination of things**

animal

walks on four legs

pet

has fur

barks

evolved from wolves

# What is a dog?

**A combination of things but some uncertainty**

what if your dog only has three legs ?

animal

walks on four legs

pet

has fur

barks

evolved from wolves

what if your dog doesn't bark, is it no longer a dog ?

# So what is a dog?!?

- Very hard for us to come up with a definition of dog even though we all know what a dog is
- How do we know when there’s so much uncertainty?
- How does our concept of dog form from other concepts like animal and pet?
- And how are we so easily able to tell the difference between a dog, cat, wolf, sheep, horse?

# Previous theories of concepts: **Symbolic approaches**

- Explicitly define the meaning of concepts
- New concepts can be created by combining existing concepts (concepts are compositional)

- **Example:**

  dog = animal + pet + walks on four legs + barks + has fur

  flying = moving in the air

  flying dog = moving in the air + animal + pet + walks on four legs + barks + has fur

- **Doesn't account for uncertainty**

  dog = animal + pet + walks on four legs + barks + has fur

  but this is not always true 

Note: Being compositional is not just adding, can do any amount of logical operations

# Previous theories of concepts: **Statistical approaches**

- Concepts have associated probabilities
- Example:
  - It’s probably true that dogs have four legs but some don’t
  - We can say that we are 80% certain that a dog has four legs
- Captures uncertainty well but can’t capture compositionality

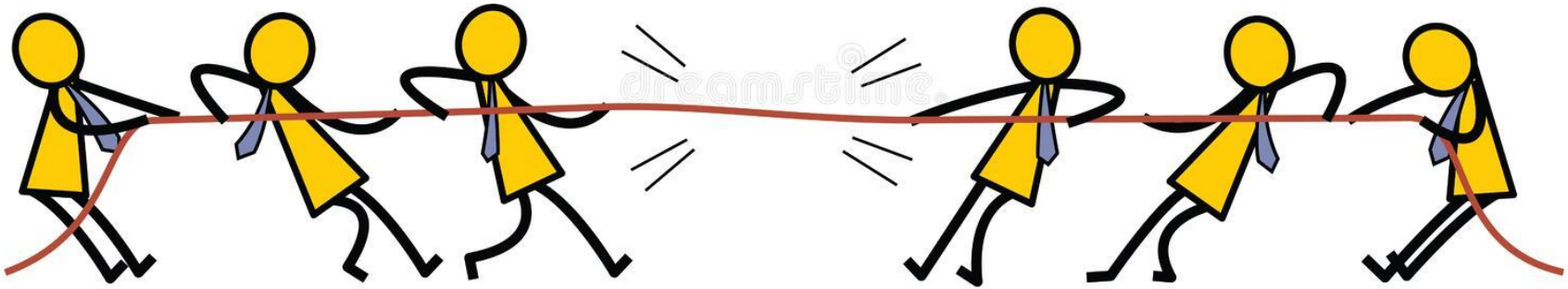
# A new theory of concepts: **Probabilistic language of thought hypothesis**

- Unifies the symbolic and statistical nature of concepts
- Because concepts are probabilities they can support reasoning under uncertainty
- And because concepts are compositional they can be combined and recombined to describe new situations
- **Example:**

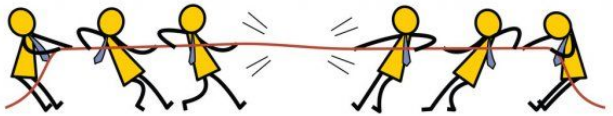
  flying dog = moving in the air + animal + pet + walks on four legs + barks + has fur + 80% confidence has four legs

# Imagine a tug of war tournament

# Imagine a tug of war tournament



Imagine a tug of war tournament



Concepts:

team

lazy

person

winner

strength

pulling

# Concepts in our computational model
(concepts are in blue)

probabilistic

```
var strength = mem(function (person) {return gaussian(50, 10)})
```

probabilistic

```
var lazy = function(person) {return flip(0.1) }
```

compositional

```
var pulling = function(person) {
  return lazy(person) ? strength(person) / 2 : strength(person) }
```

compositional

```
var totalPulling = function (team) {return sum(map(pulling, team))}
```

compositional

```
var winner = function (team1, team2) {
  totalPulling(team1) > totalPulling(team2) ? team1 : team2 }
```

# We can ask this model arbitrary queries

concepts

evidence

query

```
var tug_of_war_model = function() {
  var strength = mem(function (person) {return gaussian(50, 10)})

  var lazy = function(person) {return flip(0.1) }

  var pulling = function(person) {
    return lazy(person) ? strength(person) / 2 : strength(person) }

  var totalPulling = function (team) {return sum(map(pulling, team))}

  var winner = function (team1, team2) {
    totalPulling(team1) > totalPulling(team2) ? team1 : team2 }

  var beat = function(team1,team2){_.isEqual(winner(team1,team2), team1)}

  condition(beat(['bob', 'mary'], ['tom', 'sue']))
  condition(beat(['bob', 'sue'],  ['tom', 'jim']))

  return strength('bob')
}
```

We want to investigate if the model predictions match human predictions.

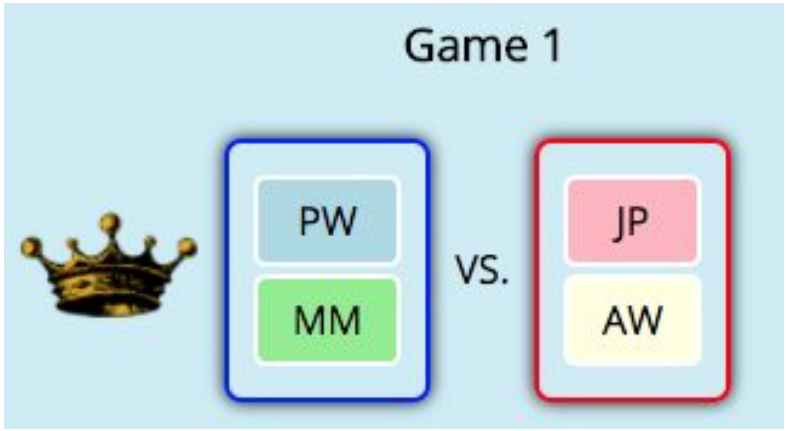
If so, that suggests that humans represent concepts in a similar way to the model.

That is, the representation of concepts in the mind is compositional and probabilistic.

So we did an experiment...

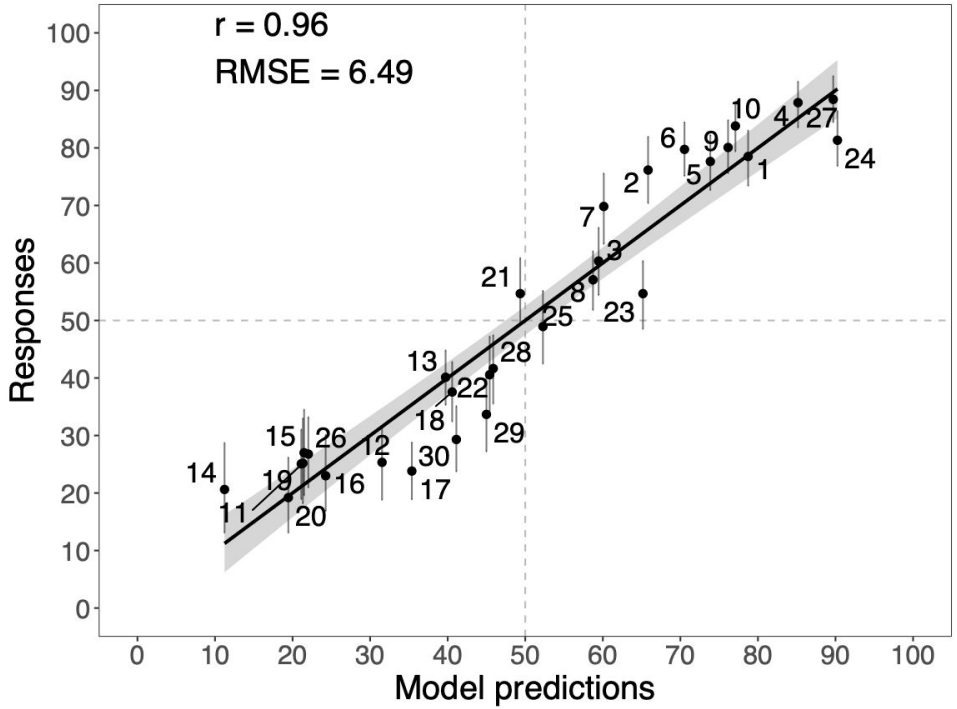
# Tug of war: Experiment 1

How strong do you think player PW is ?



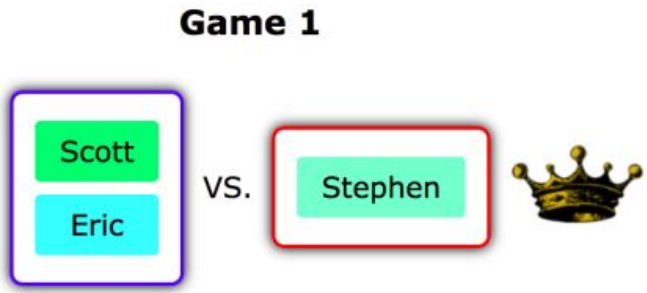

# Tug of war: Experiment 1 Results

How strong is player X



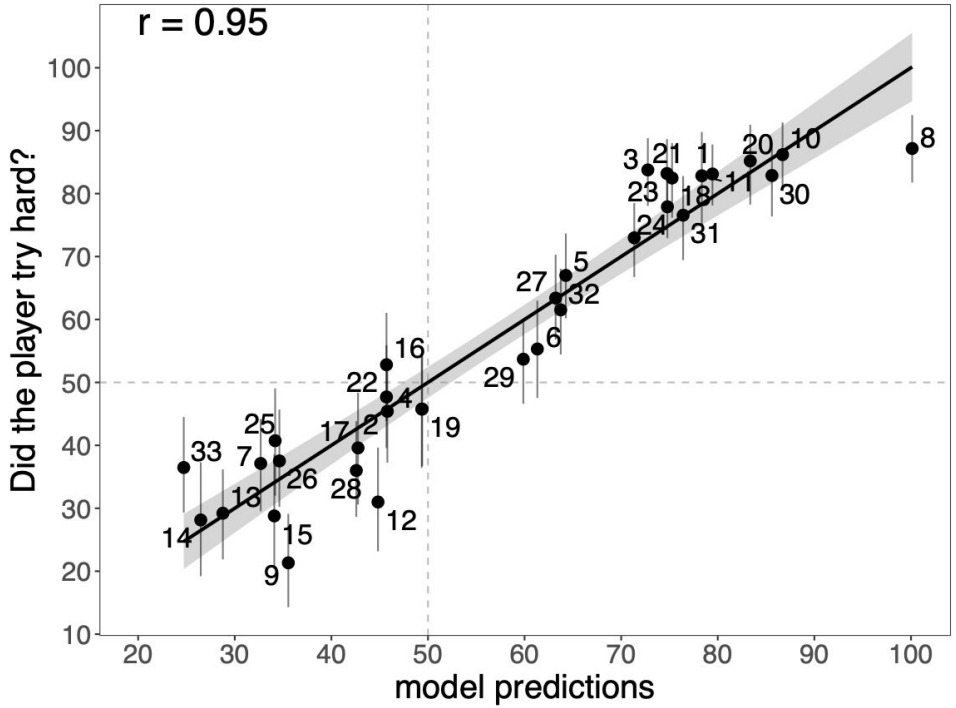
# Tug of war: Experiment 2

How likely is it that Eric tried hard in Game 1?




# Tug of war: Experiment 2 Results

## How likely is it that player X tried hard

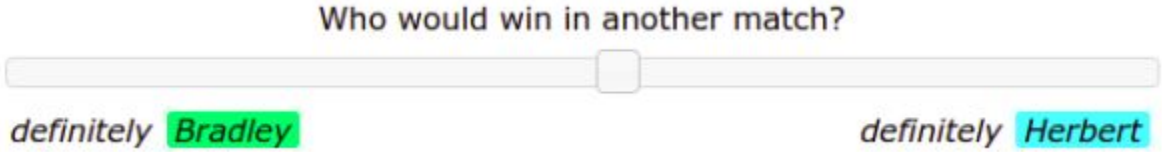


# Tug of war: Experiment 3

First answer the question based on game information, then respond to the question again after seeing the commentary

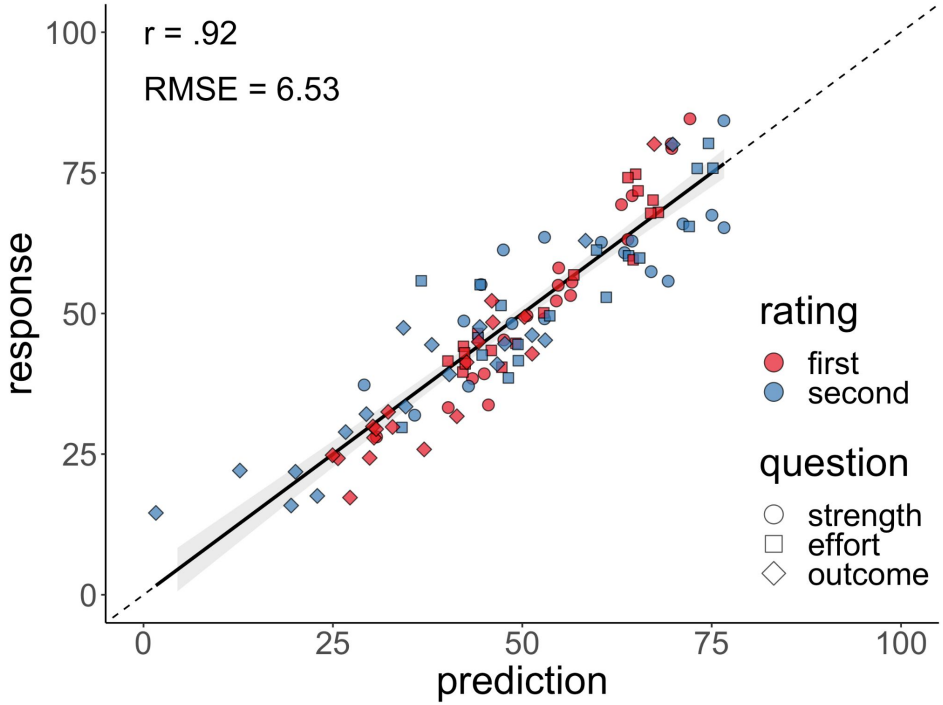
Interested in seeing how participants updated their beliefs given this new information





# Tug of war: Experiment 3 Results

## Updated beliefs



# Summary

- We still don’t understand the nature of concepts
- Two Basic Theories
  - Symbolic theories: Compositional but not probabilistic
  - Statistical theories: Probabilistic but not compositional
- Probabilistic language of thought hypothesis
  - Compositional and probabilistic !!
- Computational model that instantiates this hypothesis in a tug of war scenario
- Close correspondence between model and human predictions
- Candidate for theory of human concepts

# Acknowledgements


Thank you!

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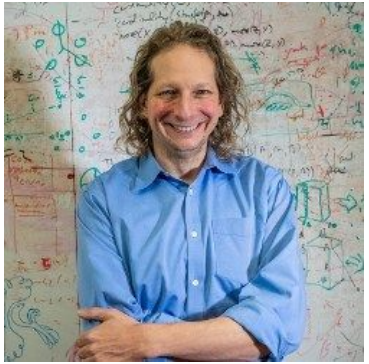

Josh Tenenbaum
MIT Brain and Cognitive Sciences

# Questions ?