

# Verb Physics

## Relative Physical Knowledge of Actions and Objects



Max Forbes



Yejin Choi



[Gao et al., 2016]



[Angeli and Manning, 2014]



[Gordon and Schubert, 2012]



[Li et al., 2014]

## *Physical properties of objects*

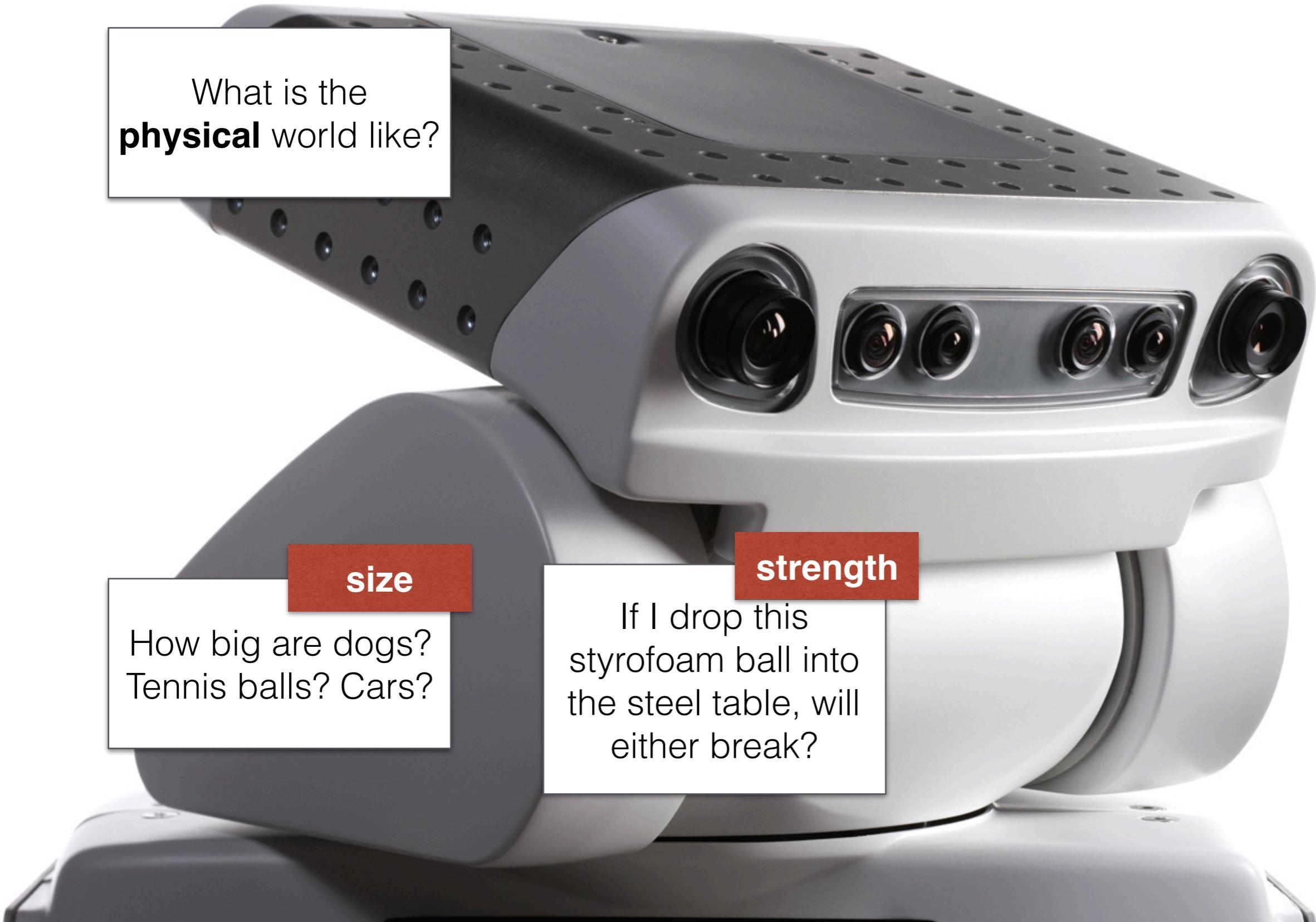
What is the  
**physical** world like?

**size**

How big are dogs?  
Tennis balls? Cars?

**strength**

If I drop this  
styrofoam ball into  
the steel table, will  
either break?



*“I am larger than a chair”*

~~"I am larger than a chair"~~

~~“I am larger than a pen”~~

~~“I am larger than a stone”~~

~~“I am larger than a chair”~~

~~“I am larger than a ball”~~

~~“I am larger than a towel”~~

*“The horse was as  
small as a dog!”*

⇒ horse =<sup>size</sup> dog ?



*“Hey robot, pass me the <unk>.”*

*“OK.” (attempts to pick up table)*

**"I *picked up* the <thing>."**

**"I took a *drink from* the <thing>."**

**"The <thing> *shattered* when it hit the ground"**



# Two related problems

*Physical properties implied by predicates*

“I **picked up** the <thing>.”

“I took a **drink from** the <thing>.”

“The <thing> **shattered** when it hit the ground

*Physical properties of objects*

size



strength

weight



1. Introduction
2. Related work
3. Approach
4. Model
5. Data
6. Evaluation

# Pattern-based IE

[Gordon et al., 2010]

[Gordon and Schubert, 2012]

*“how often do  
you sleep?”*



# Word embeddings

[Rubinstein et al., 2015]

*“is yellow”    “is large”*



# Commonsense knowledge base completion

[Angeli and Manning, 2013]

[Li et al., 2016]

[Angeli and Manning, 2014]

*“not all birds can fly”*



## Verbs grounded in robotics + vision

[Tellex et al., 2011]

[Misra et al., 2014]

[She and Chai, 2016]

[Gao et al., 2016]

*“cutting changes the number of pieces”*

## Semantic proto-roles

[Dowty, 1991]

[Kako, 2006]

[Reisinger et al., 2015]

## Overcoming reporting bias

[Sorower et al., 2011]

[Misra et al., 2016]

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# Two related problems

*Physical properties implied by predicates*

“I **picked up** the <unk>.”

“I took a **drink from** the <unk>.”

“The <unk> **shattered** when it hit the ground

*Physical properties of objects*

size



weight



strength

# Attributes

$x > \text{size}$        $y$



$x > \text{weight}$        $y$



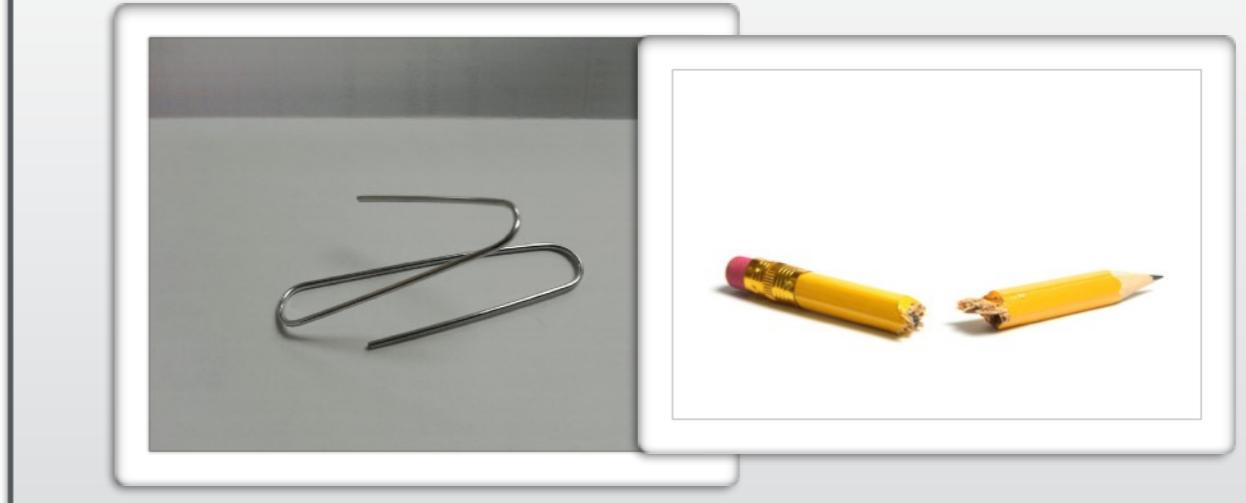
$x > \text{speed}$        $y$



$x > \text{strength}$        $y$



$x < \text{rigidness}$        $y$



*“I threw the \_\_\_\_\_”*

*“I threw the \_\_\_\_\_,”*

*ball*

*stone*

*chair*

*“I threw the \_\_\_\_\_”*

*ball*

*stone*

*chair*

*game*

*party*



*“I threw the \_\_\_\_\_,”*

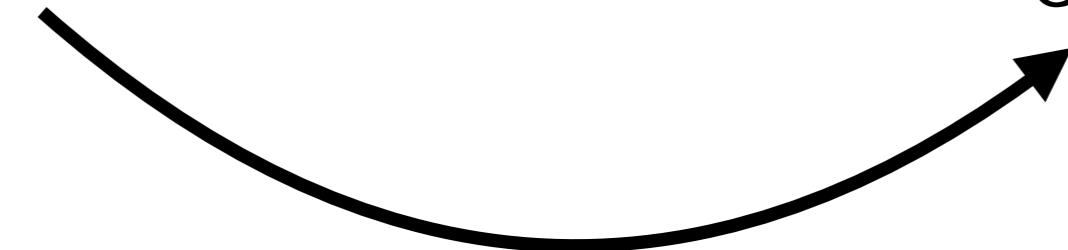
*ball*

*stone*

*chair*

*x*    threw    *y*

*x*    threw    *y*



*x* is bigger than *y*



$x$  is bigger than  $y$

$x$  weighs more than  $y$

as a result,  $y$  will be moving faster than  $x$

## Action frame

$x$     threw     $y$

$\Rightarrow x >^{\text{size}} y$

$\Rightarrow x >^{\text{weight}} y$

$\Rightarrow x <^{\text{speed}} y$

# Terminology

**Action frames** — *simple syntax-based verb constructions  
that compare two objects*

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**Action frames** — *simple syntax-based verb constructions that compare two objects*

$x$  threw  $y$   
PERSON threw  $x$  into  $y$   
PERSON threw on  $x$

*distinct action frames for the same verb*

# Terminology

**Action frames** — *simple syntax-based verb constructions  
that compare two objects*

$x$  threw  $y$

PERSON threw  $x$  into  $y$

PERSON threw on  $x$

**Objects** — *non-abstract nouns*

✓ ball      ✗ ~~evil~~

✓ train      ✗ ~~time~~

# Two related problems

*Physical properties implied by predicates*

“I **picked up** the <thing>.”

“I took a **drink from** the <thing>.”

“The <thing> **shattered** when it hit the ground

*Physical properties of objects*

size



weight



strength

# Two related problems

*Physical properties implied by predicates*

*Physical properties of objects*

## Example

takes values in  $\{\triangleright, \triangleleft, \approx\}$

$F$  = “ $x$  threw  $y$ ”

attribute: size

correct value:  $\triangleright$

intuition: “ $x$  threw  $y$ ”

$\implies x >^{\text{size}} y$

size



strength

weight



# Two related problems

*Physical properties implied by predicates*

Example

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*Physical properties of objects*

Example

takes values in  $\{\triangleright, \triangleleft, \approx\}$

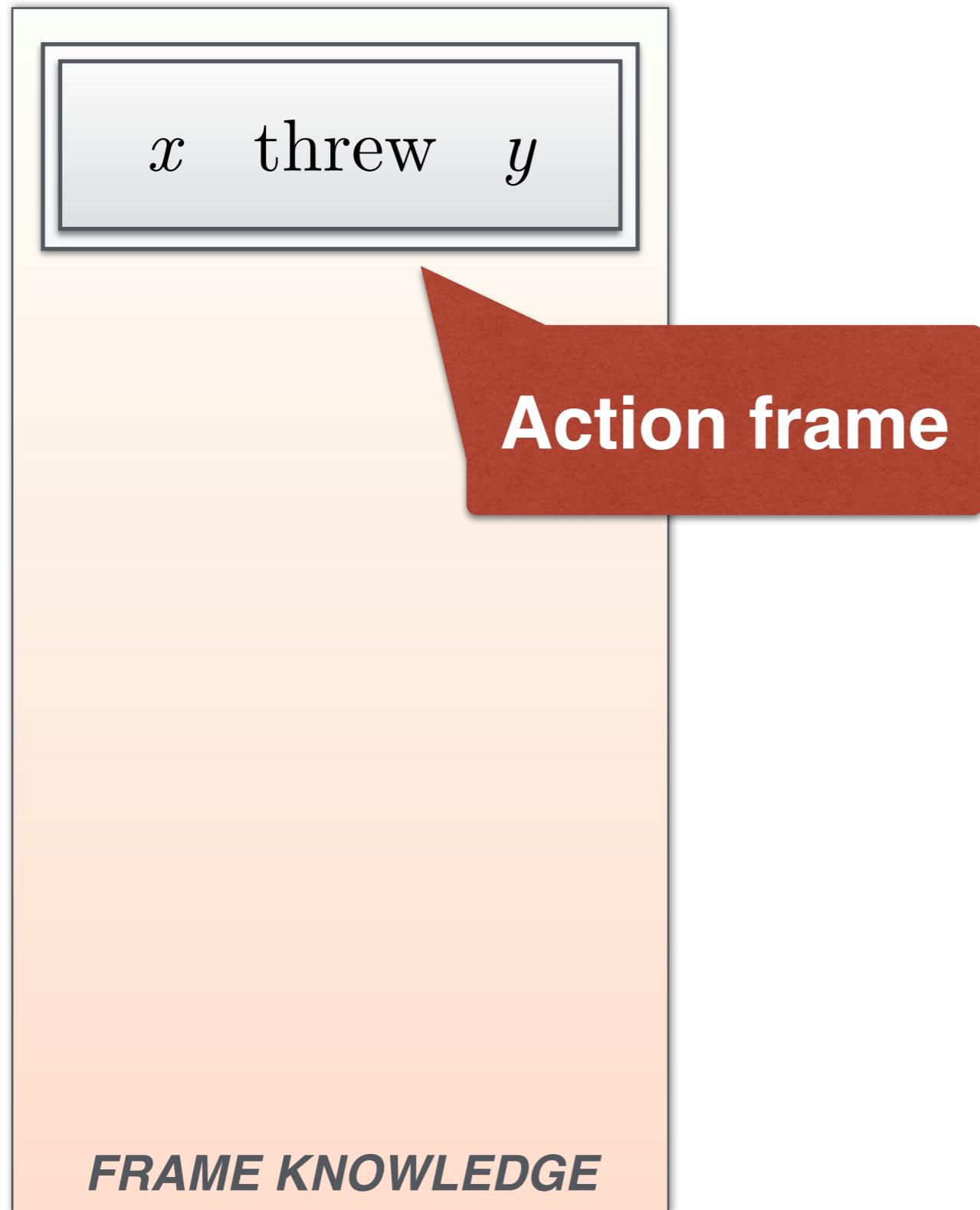
$J_{p,q}$  = (person, ball)

attribute: size

correct value:  $\triangleright$

intuition: people are generally larger than balls

# Solving both puzzles together



# Solving both puzzles together

$x$  threw  $y$

**FRAME KNOWLEDGE**

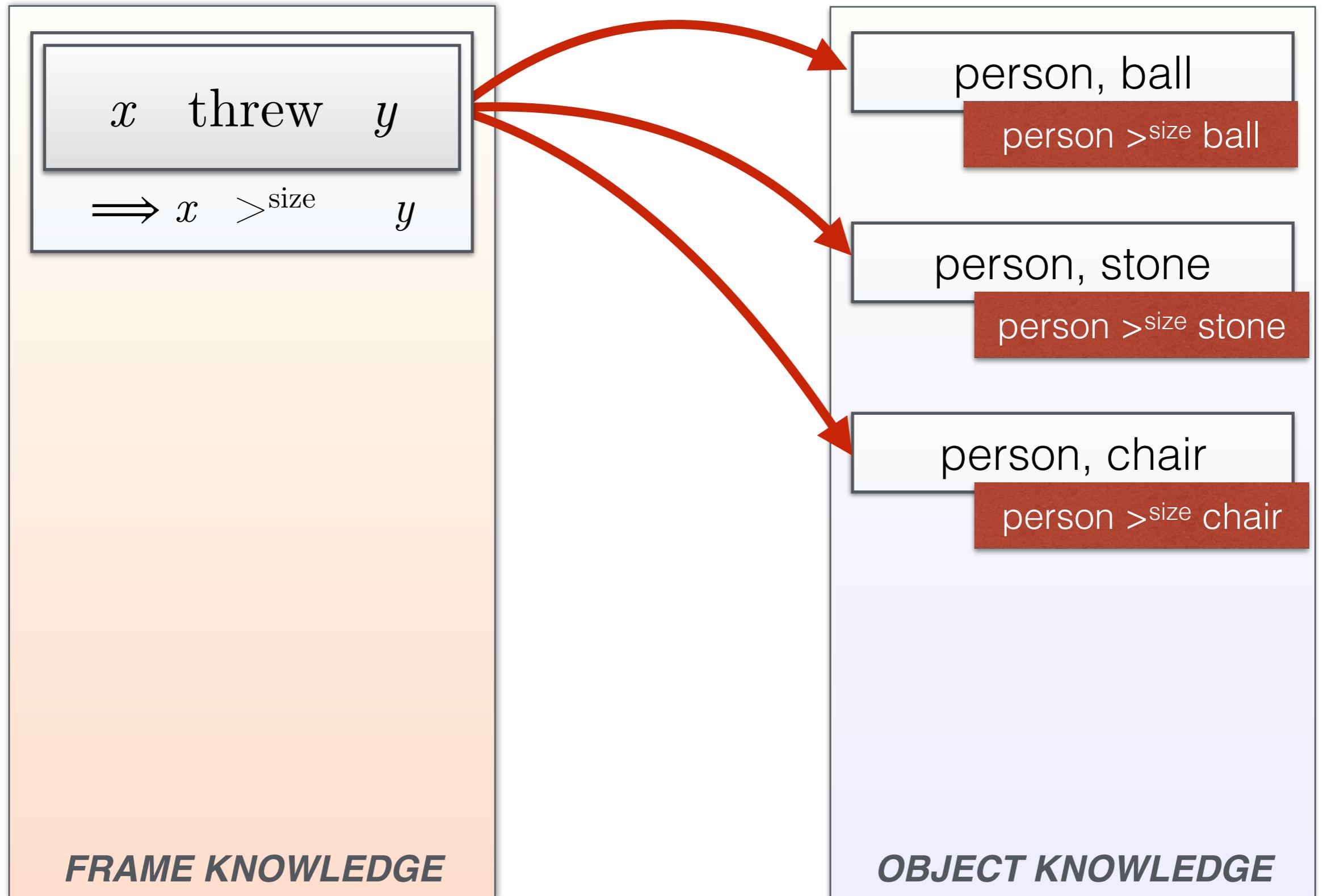
person, ball

person, stone

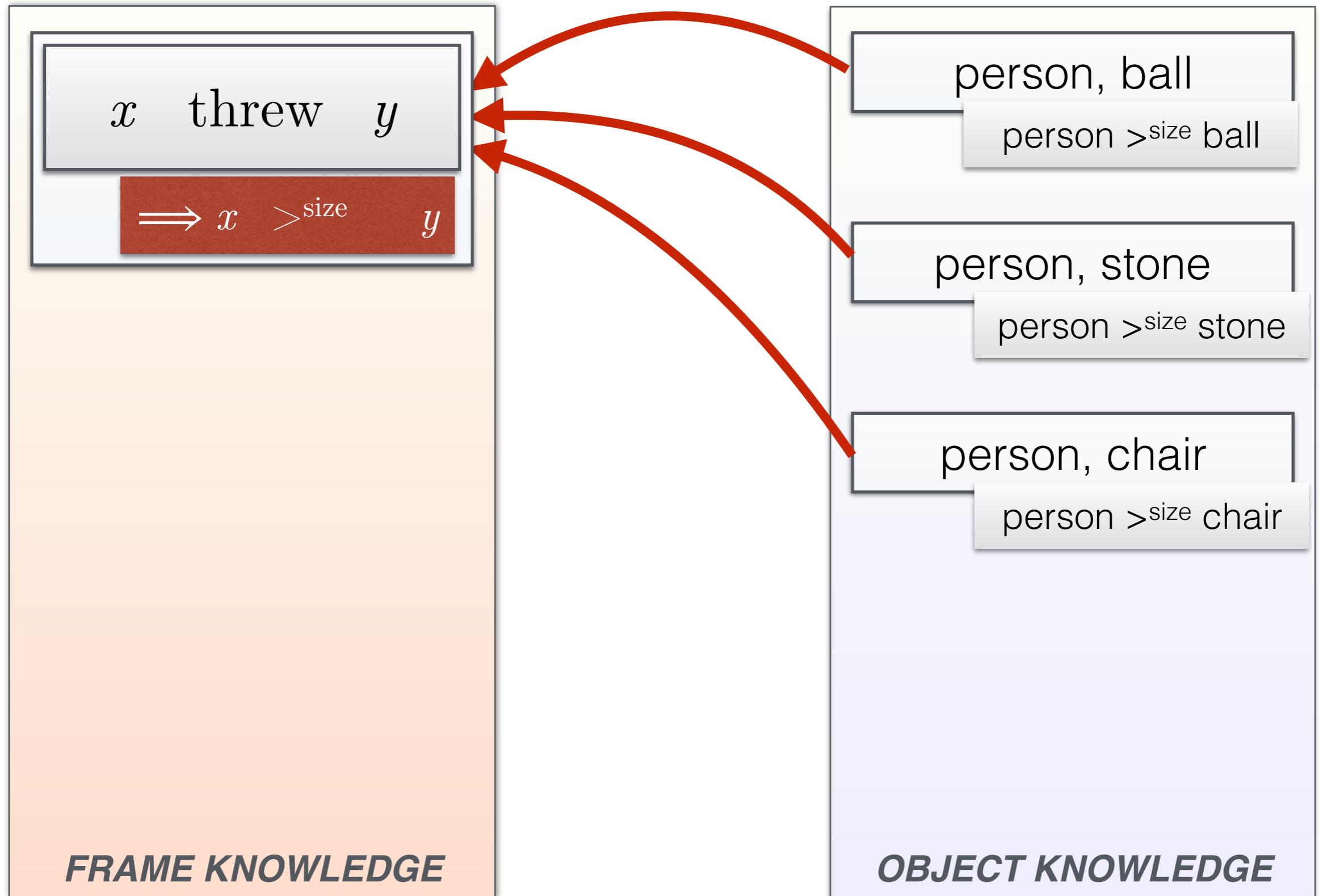
person, chair

**OBJECT KNOWLEDGE**

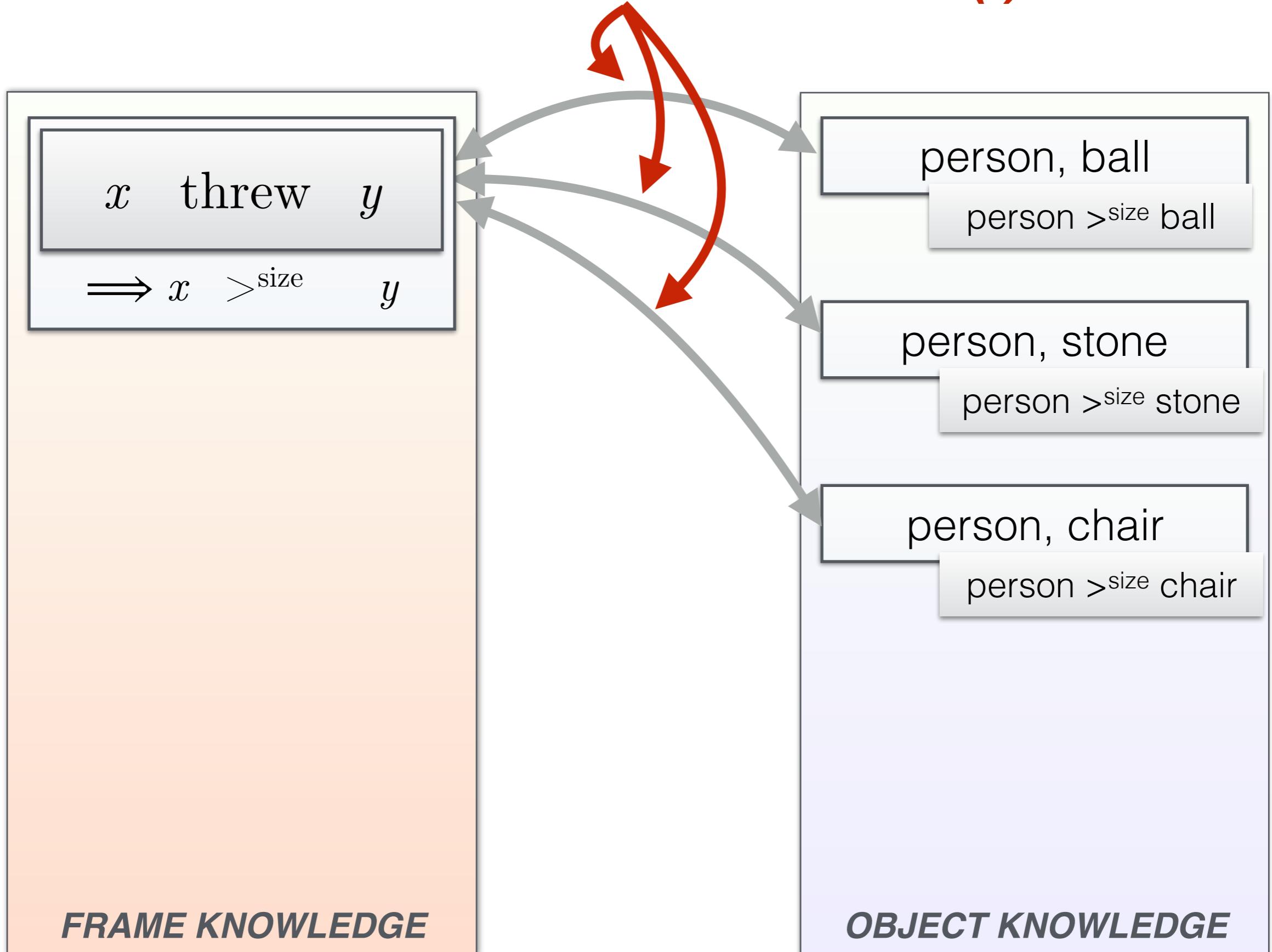
# Solving both puzzles together



# Solving both puzzles together

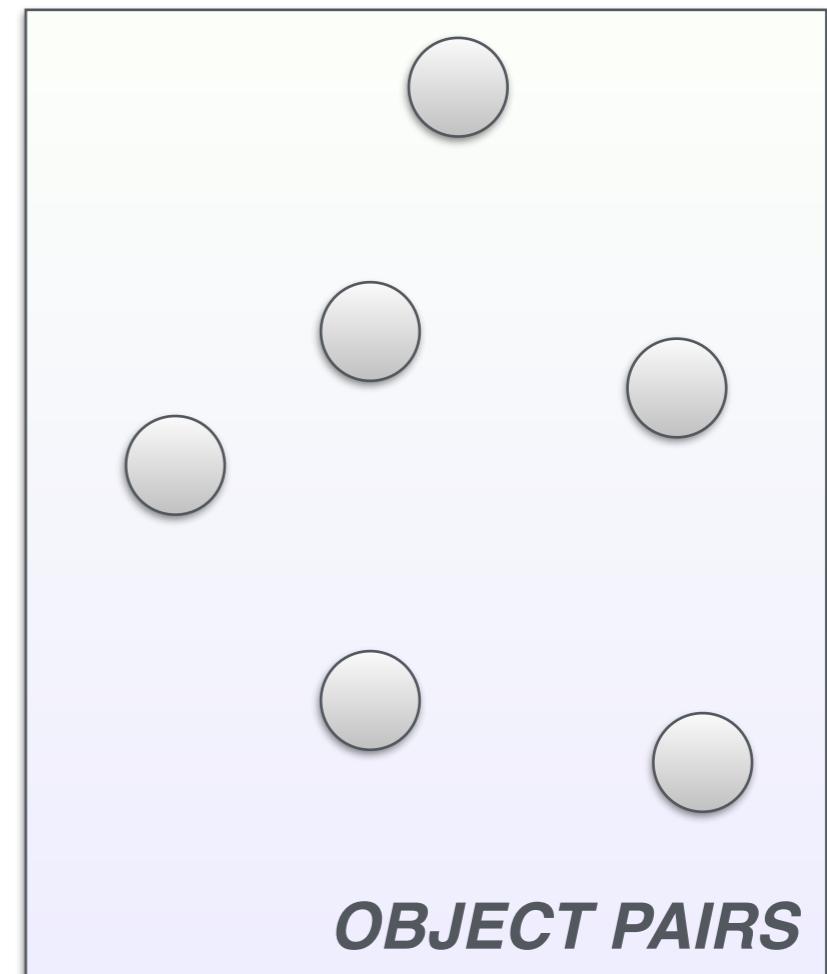
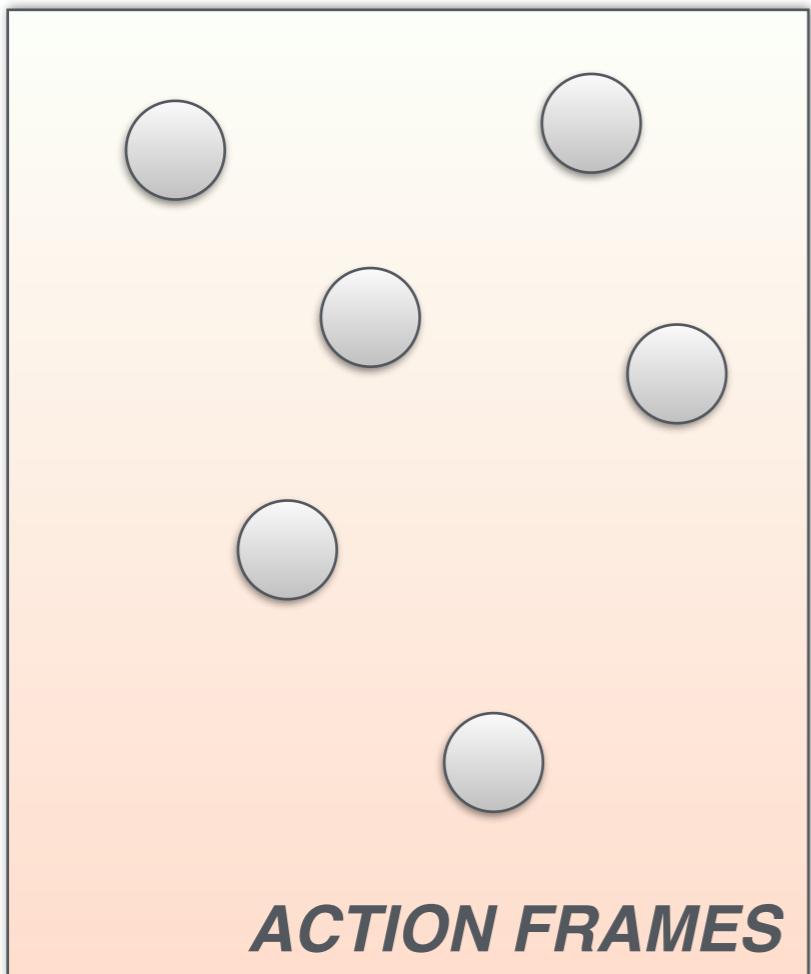


# **OBSERVABLE IN LANGUAGE (!)**

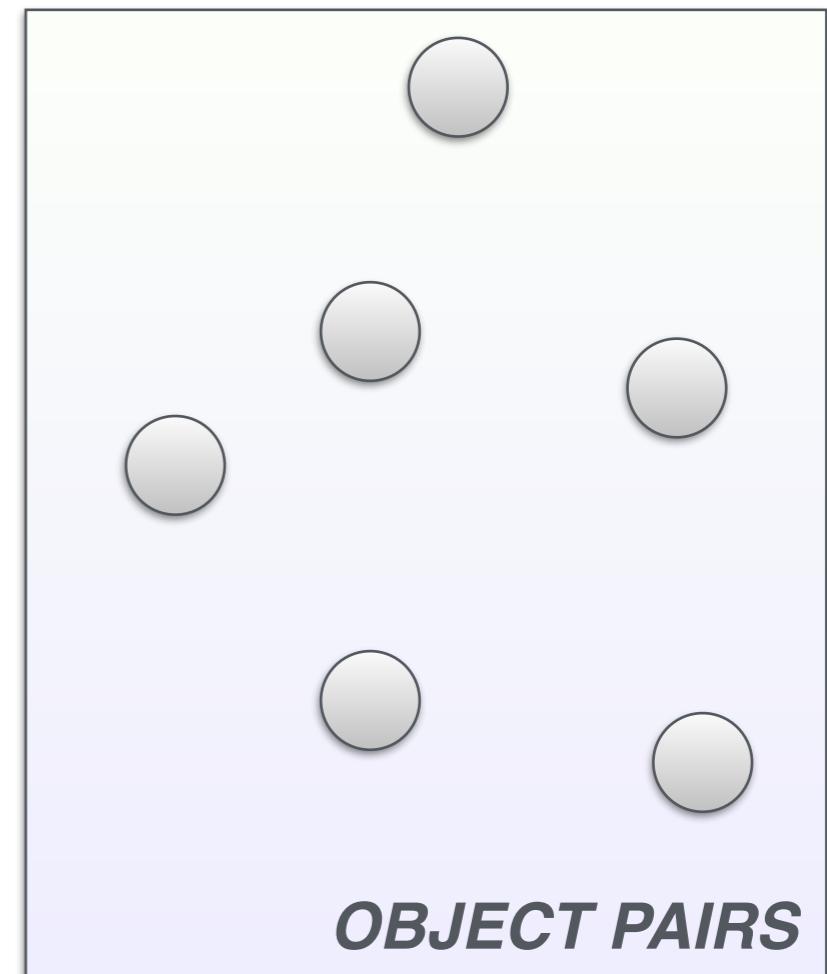
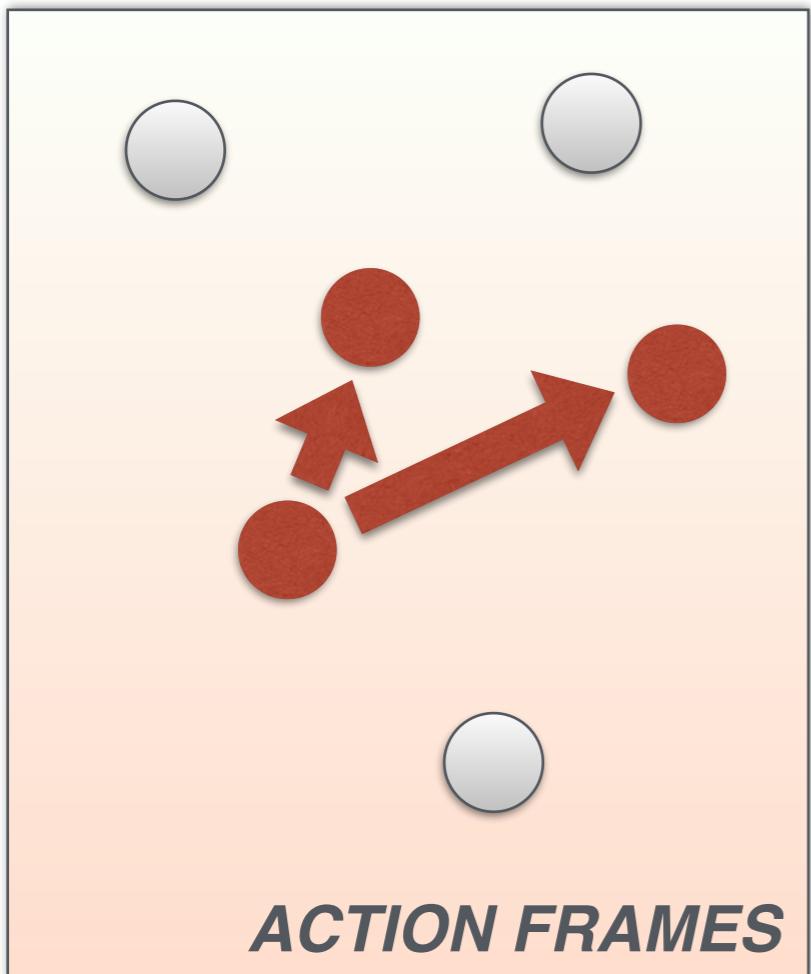


1. Introduction
2. Related work
3. Approach
- 4. Model**
5. Data
6. Evaluation

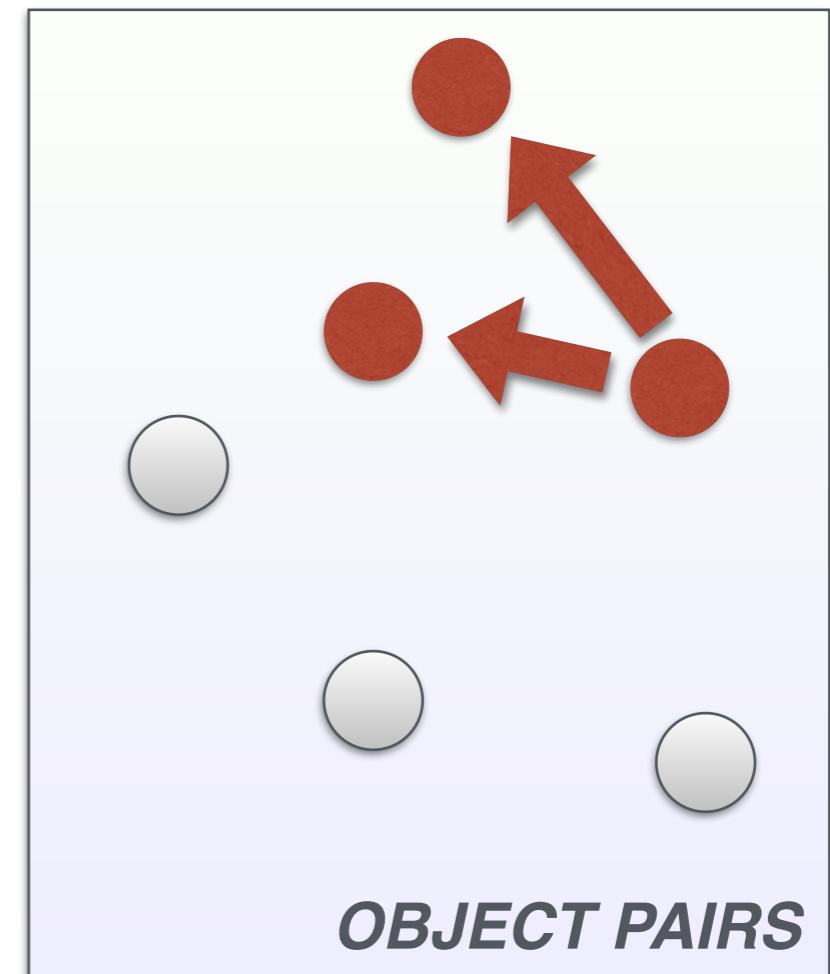
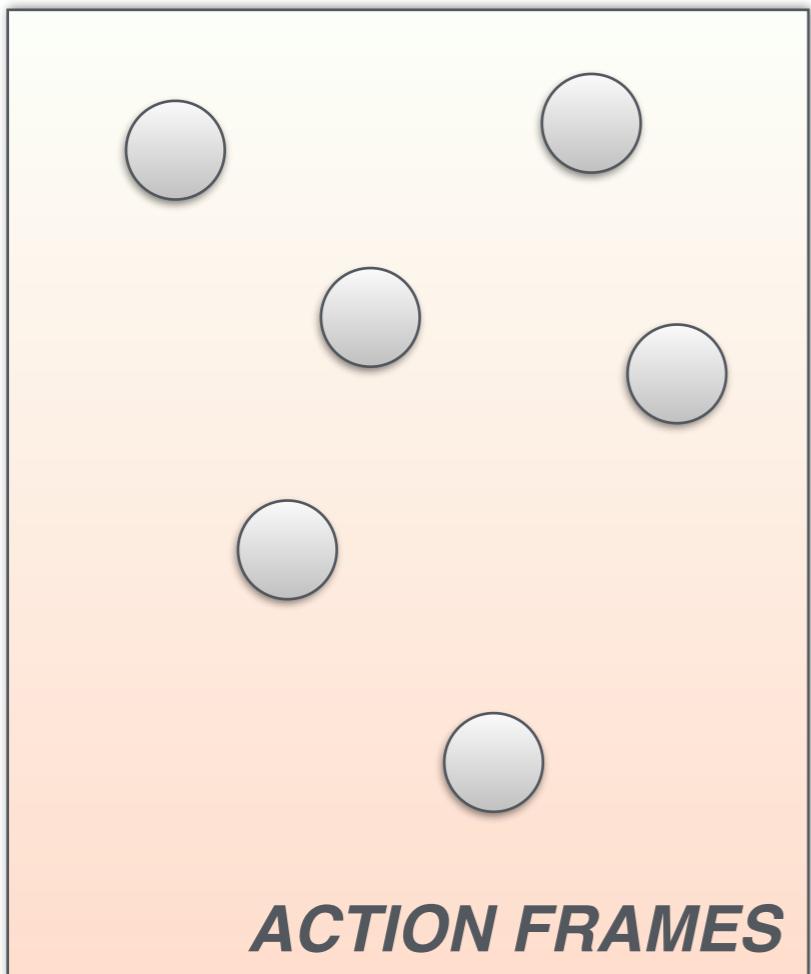
# High level model



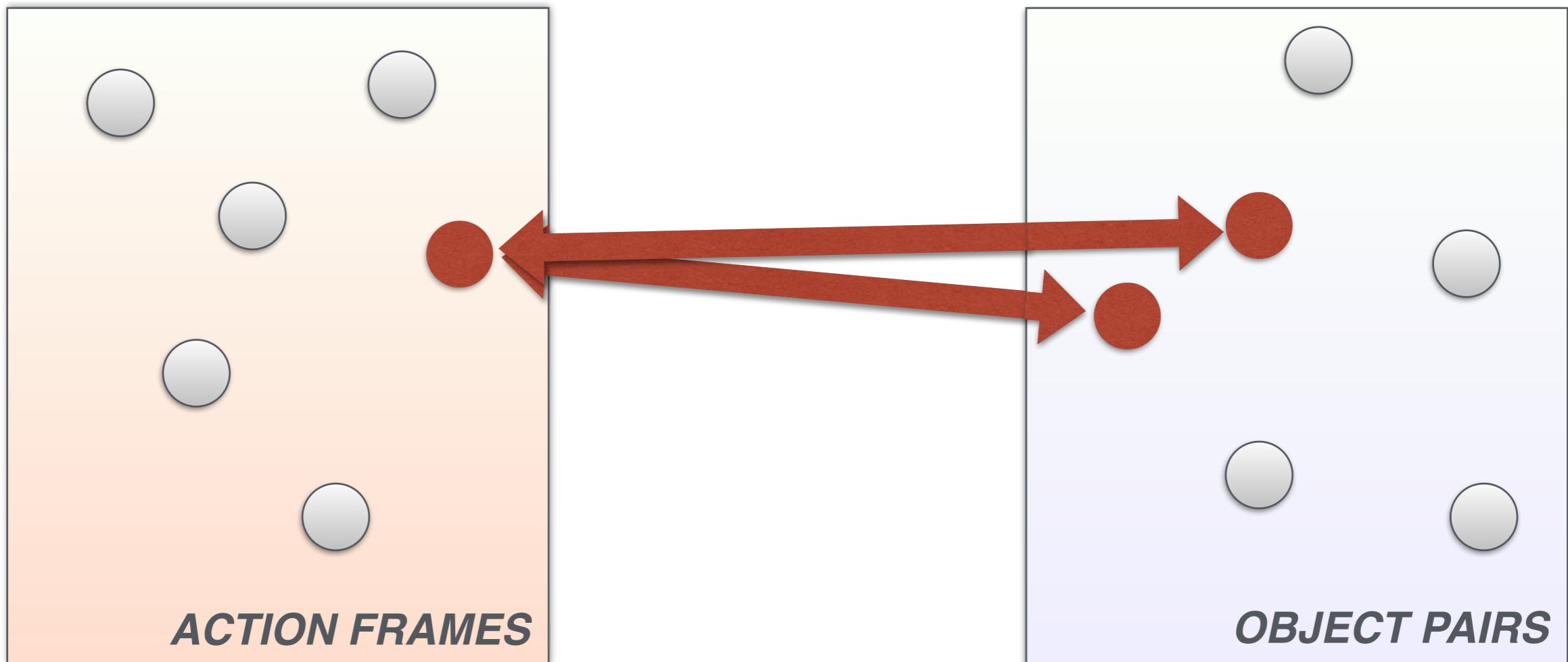
# High level model



# High level model

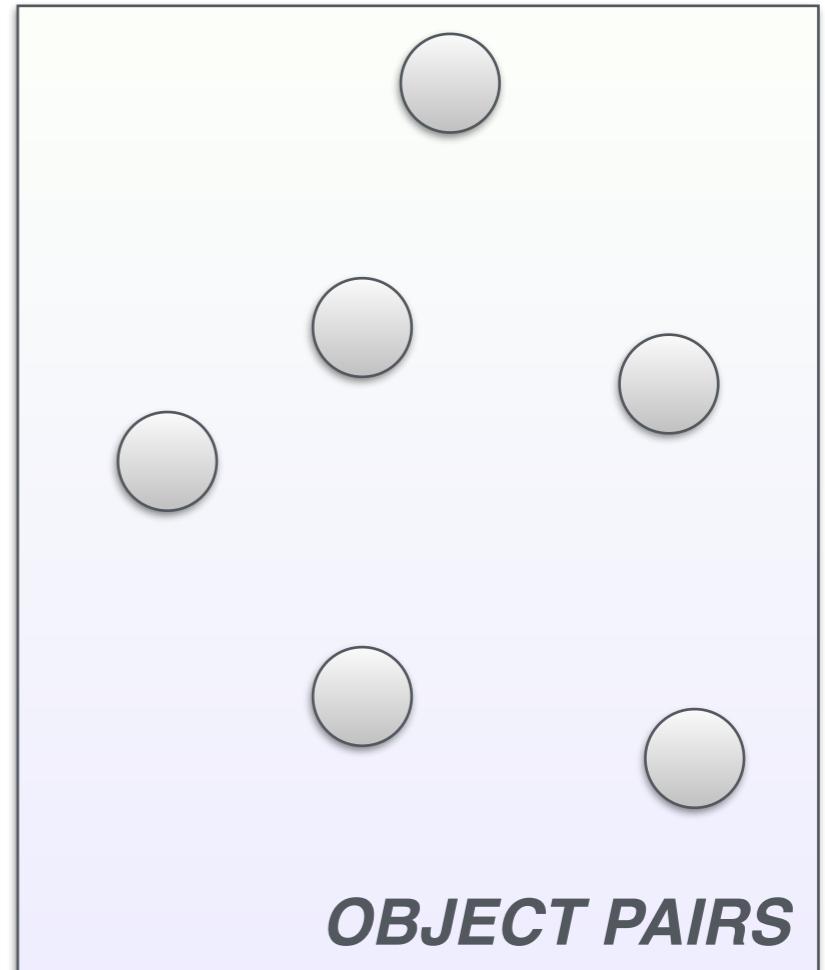
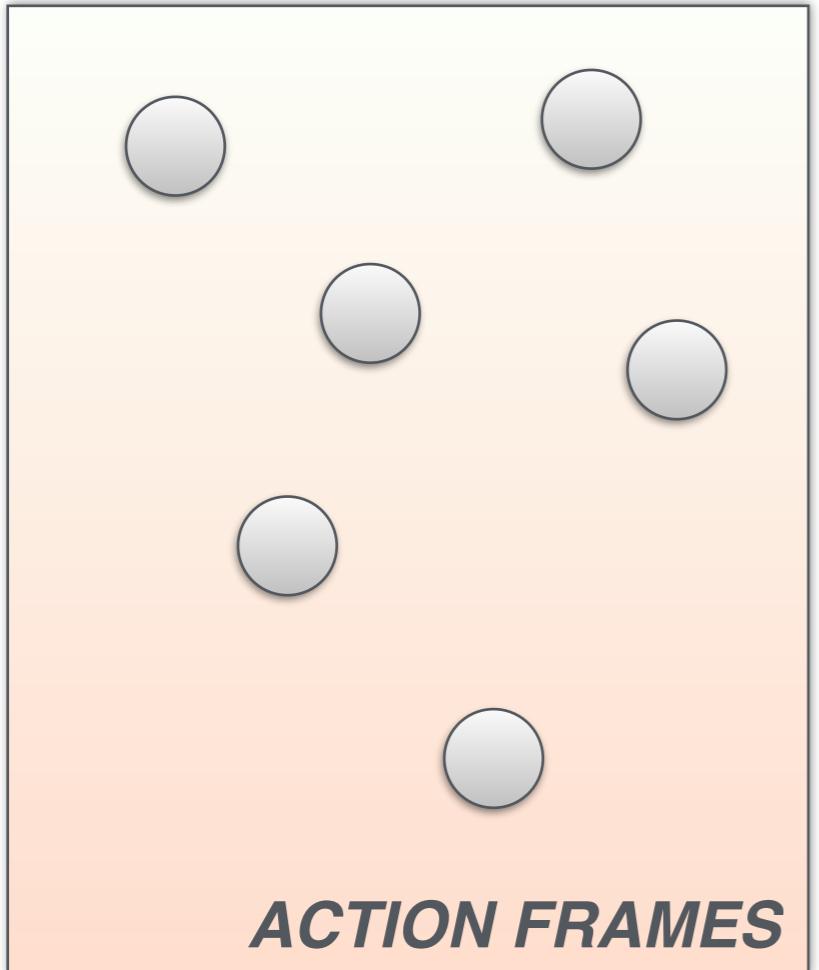


# High level model



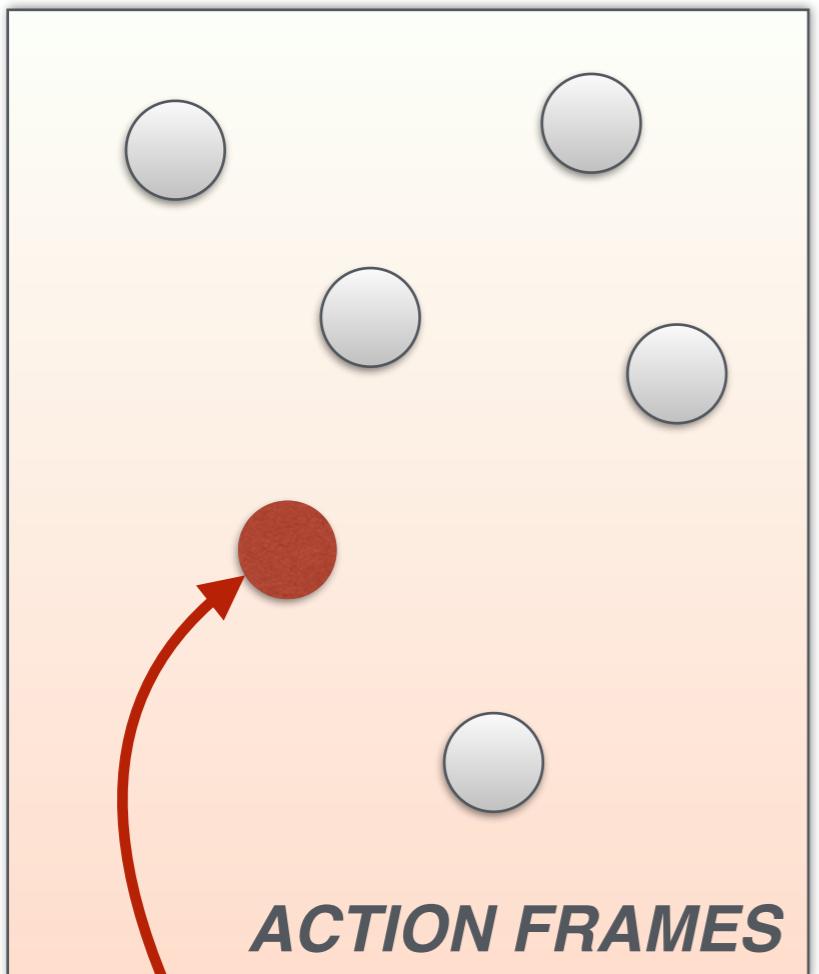
Random variables  $F_{v_t}^a$

Take values in  $\{\triangleright, \triangleleft, \approx\}$

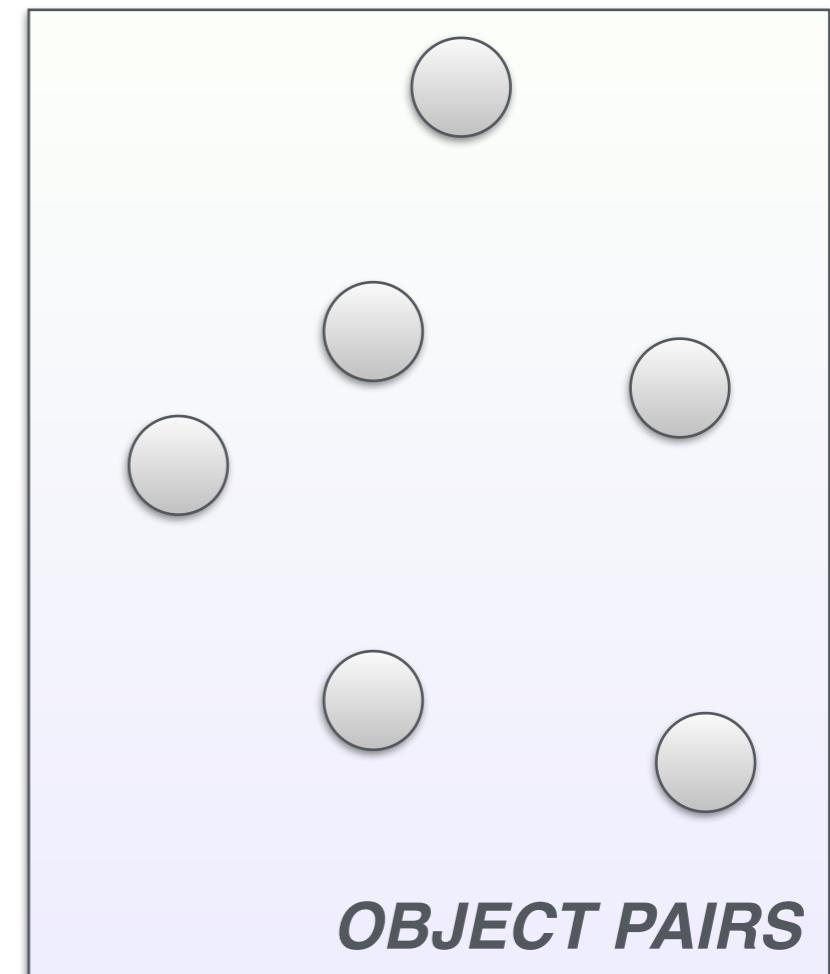


Random variables  $F_{v_t}^a$

Take values in  $\{\triangleright, \triangleleft, \approx\}$



**ACTION FRAMES**

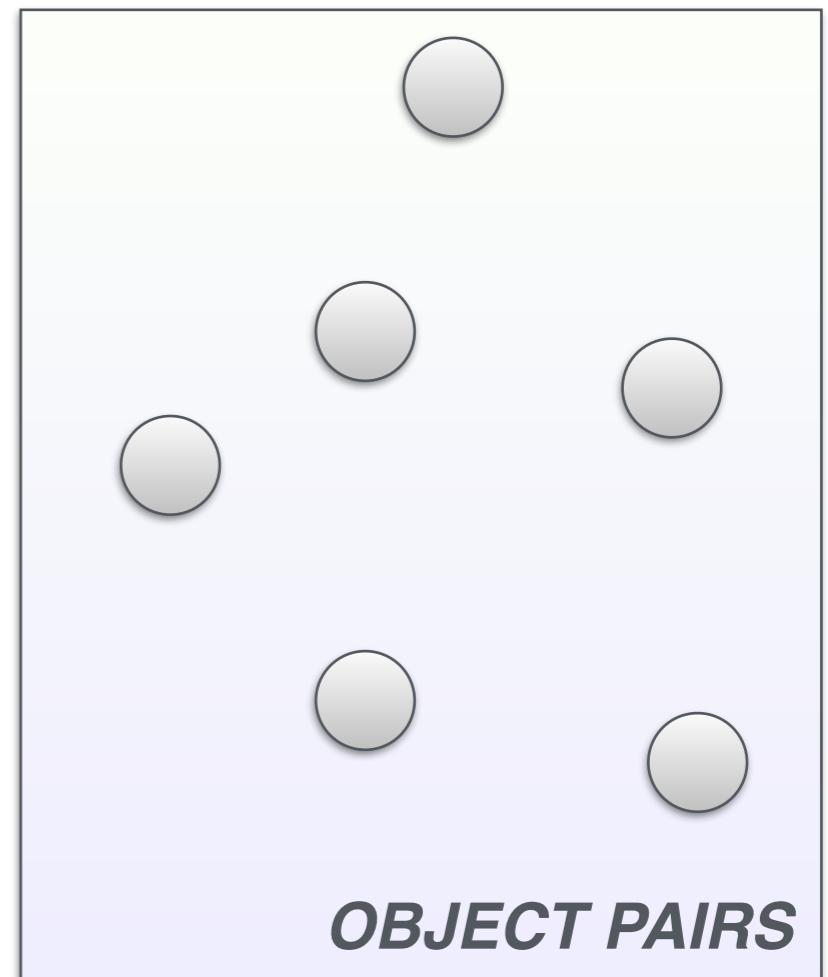
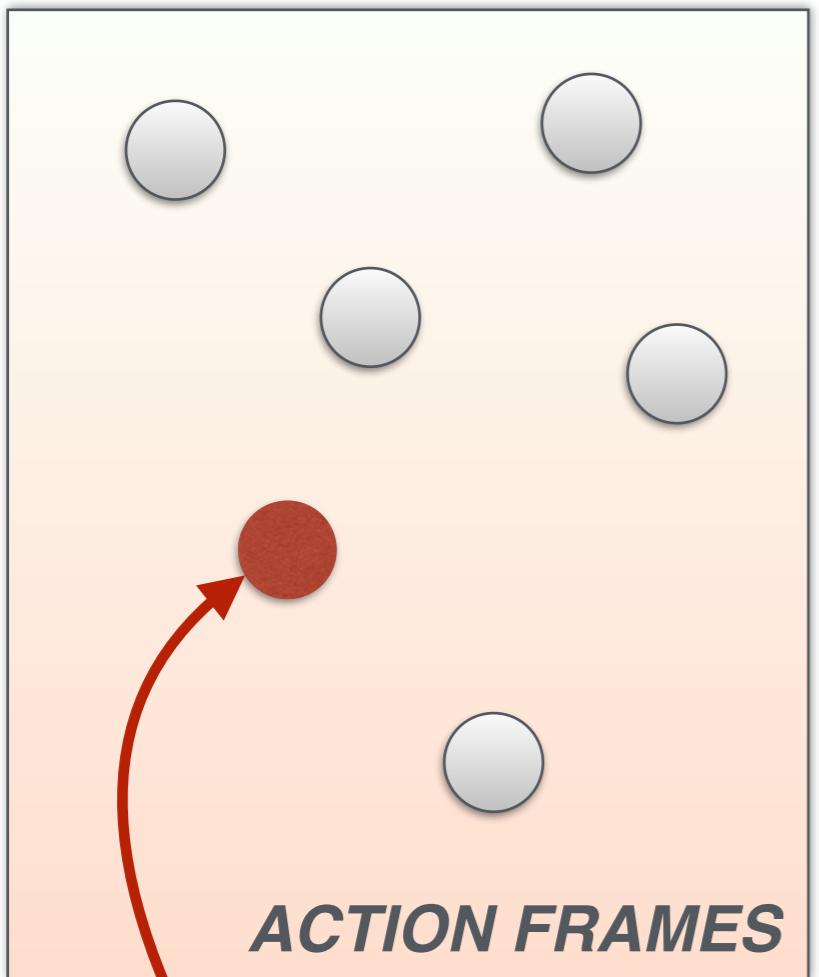


**OBJECT PAIRS**

$F_{\text{threw}_1}^{\text{size}} \approx \text{"x threw y"}$

Random variables  $F_{v_t}^a$

Take values in  $\{\boxed{>}, \boxed{<}, \boxed{\approx}\}$

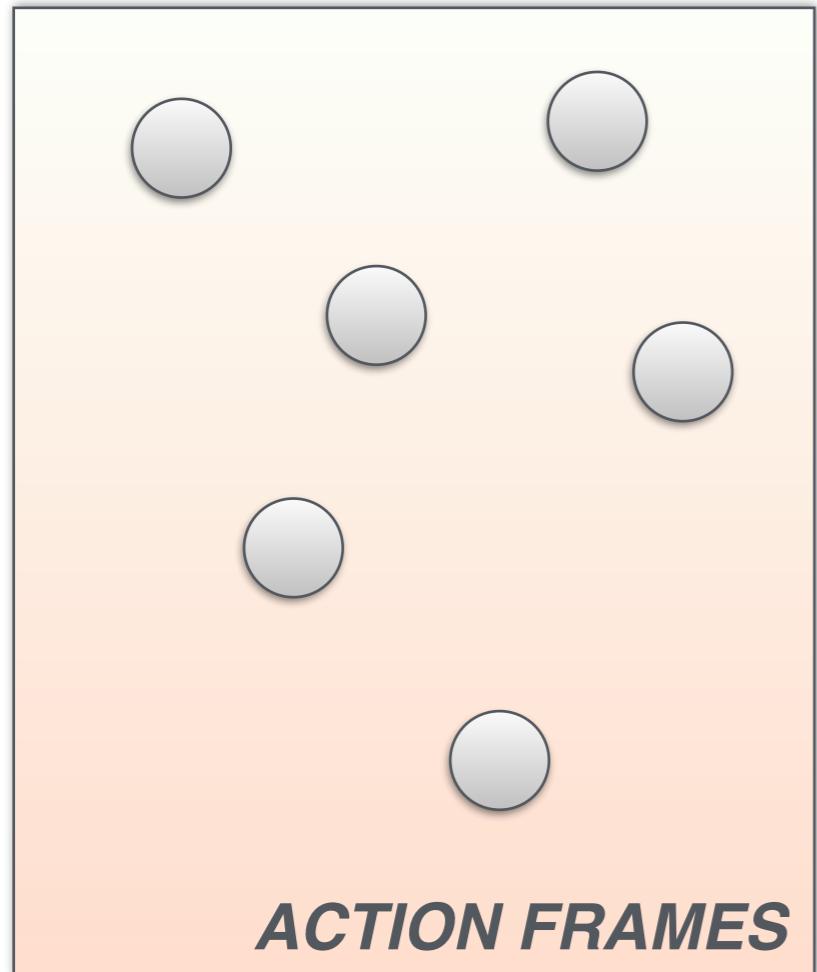


$F_{\text{threw}_1}^{\text{size}} \approx \text{"x threw y"}$

$p(F_{\text{threw}_1}^{\text{size}} = \boxed{>}) := p(\text{"x threw y"} \Rightarrow x >^{\text{size}} y)$

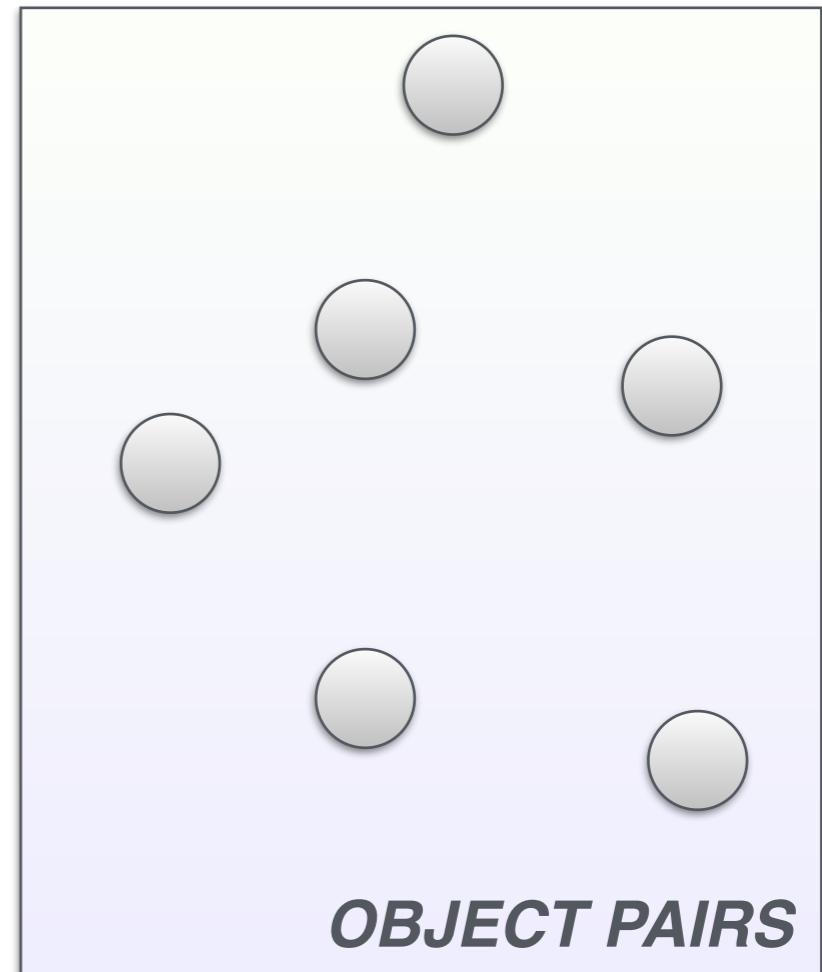
Random variables  $F_{v_t}^a$

Take values in  $\{\boxed{>}, \boxed{<}, \boxed{\approx}\}$



Random variables  $J_{p,q}^a$

Take values in  $\{\boxed{>}, \boxed{<}, \boxed{\approx}\}$

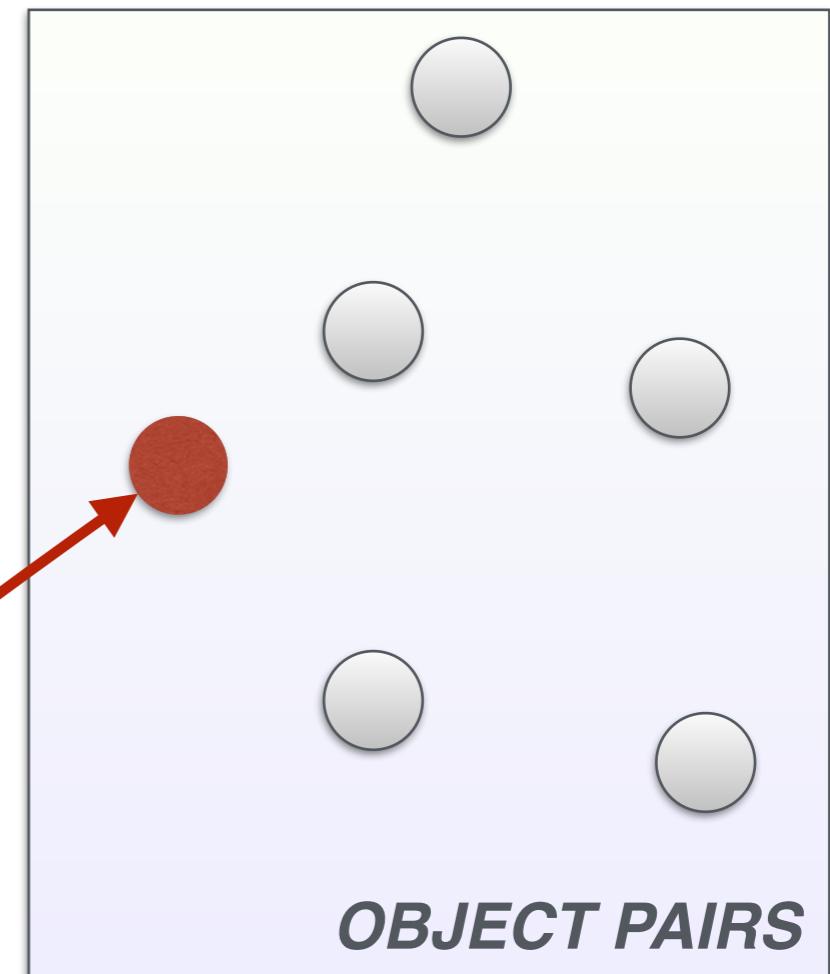
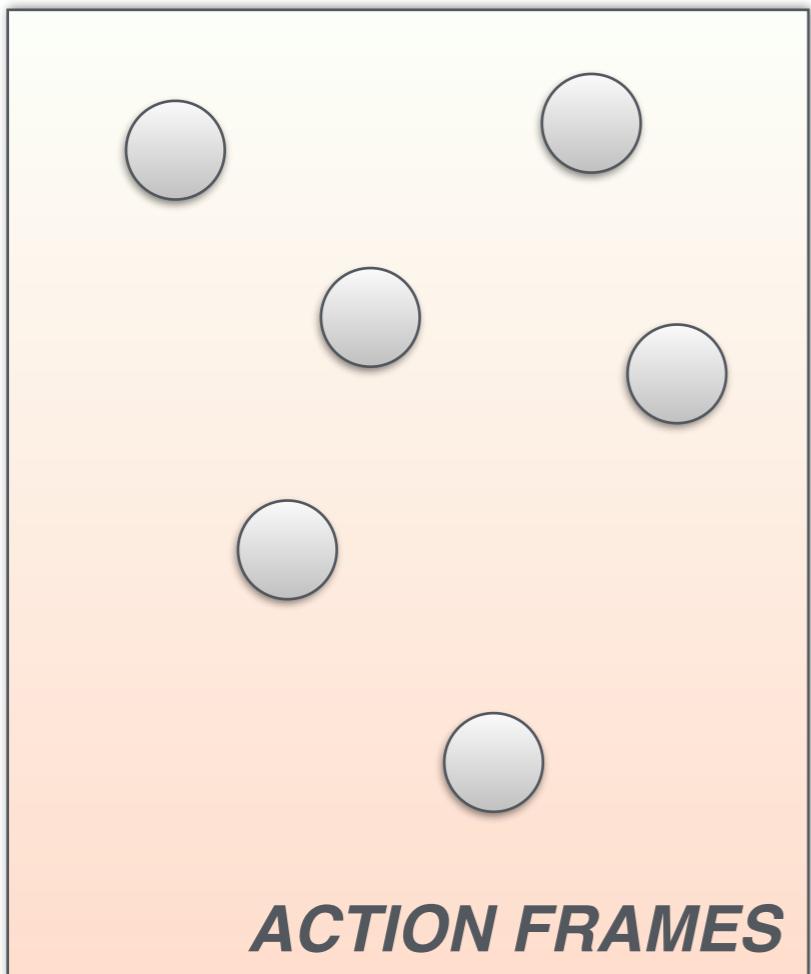


Random variables  $F_{v_t}^a$

Take values in  $\{\boxed{>}, \boxed{<}, \boxed{\approx}\}$

Random variables  $J_{p,q}^a$

Take values in  $\{\boxed{>}, \boxed{<}, \boxed{\approx}\}$



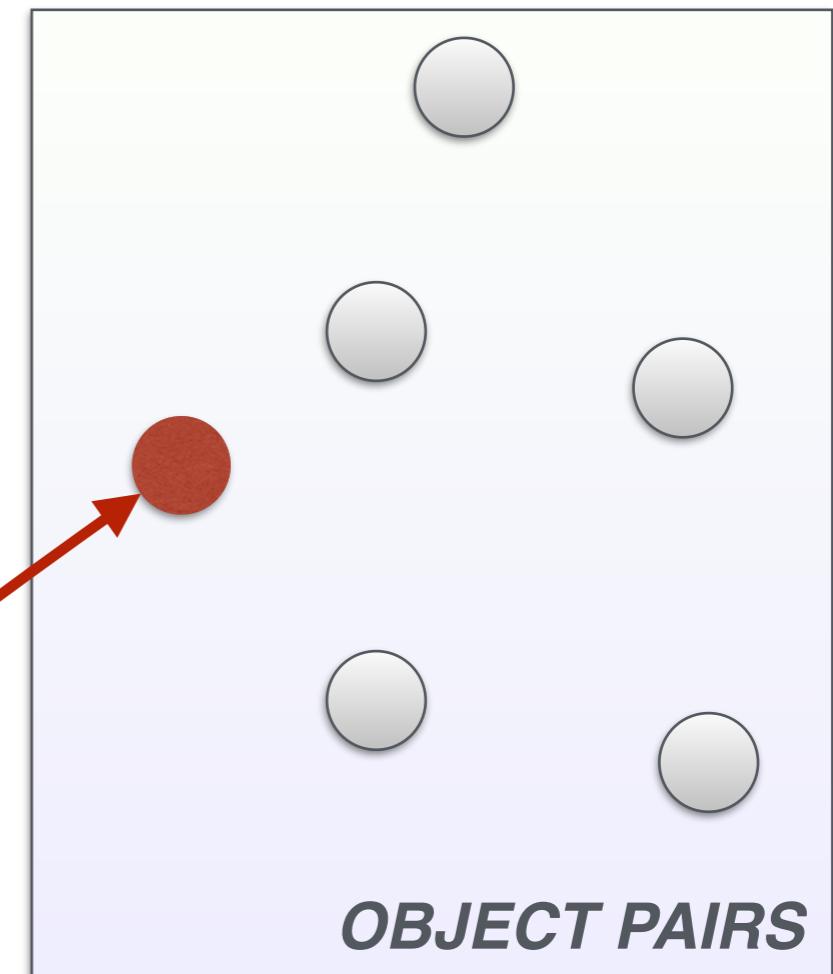
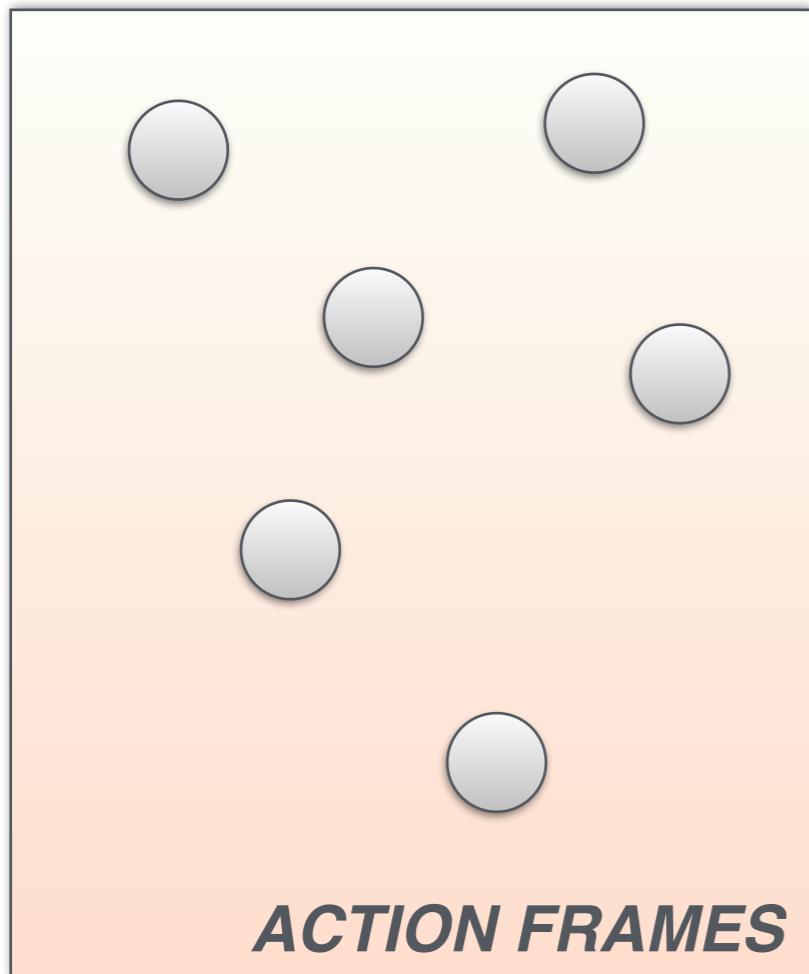
$$J_{\text{PERSON}, \text{ball}}^{\text{size}} \approx (\text{PERSON}, \text{ball})$$

Random variables  $F_{v_t}^a$

Take values in  $\{\boxed{>}, \boxed{<}, \boxed{\approx}\}$

Random variables  $J_{p,q}^a$

Take values in  $\{\boxed{>}, \boxed{<}, \boxed{\approx}\}$

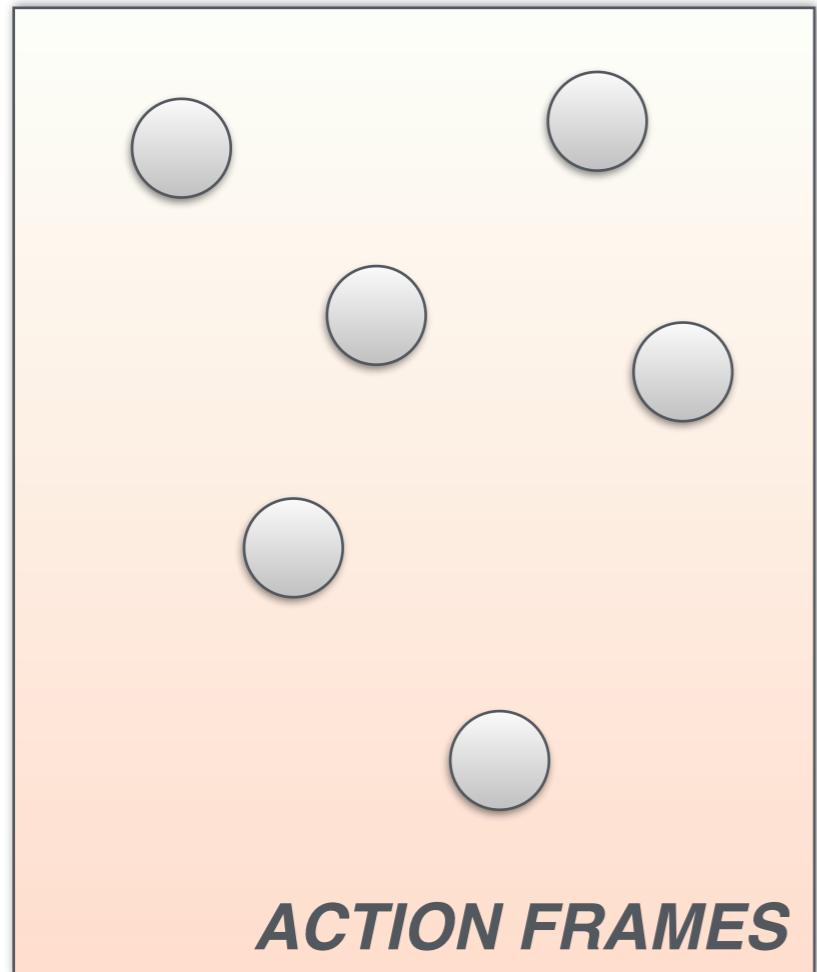


$$J_{\text{PERSON}, \text{ball}}^{\text{size}} \approx (\text{PERSON}, \text{ball})$$

$$p(J_{\text{PERSON}, \text{ball}}^{\text{size}} = \boxed{>}) := p(\text{PERSON} >^{\text{size}} \text{ball})$$

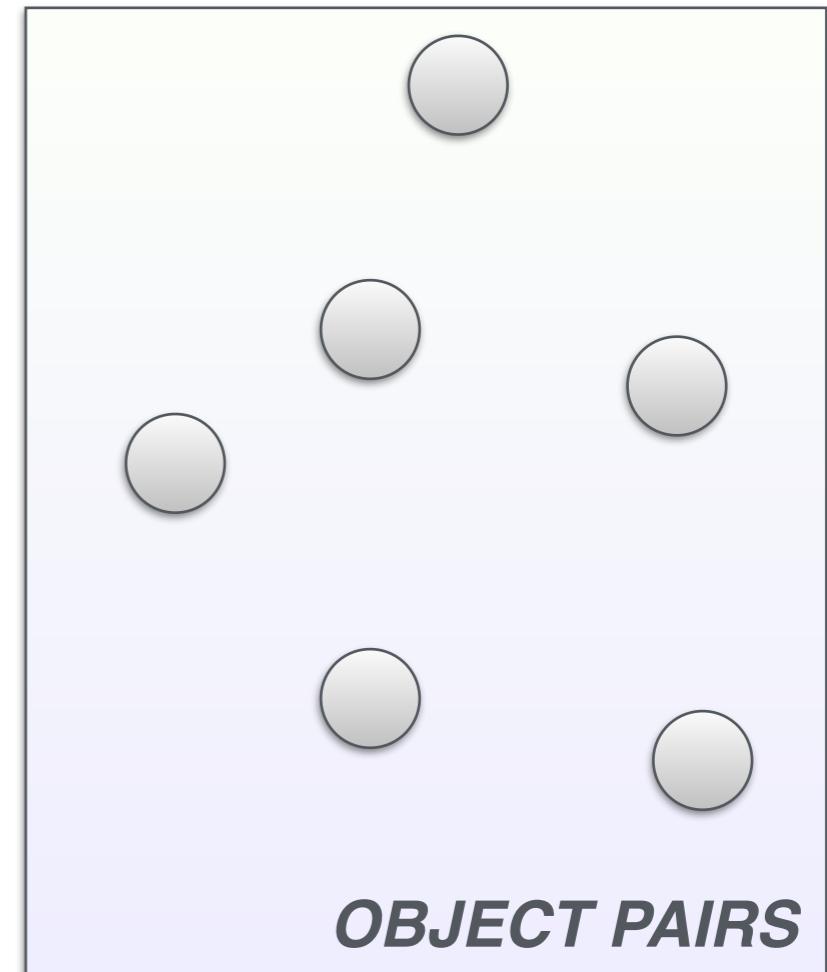
Random variables  $F_{v_t}^a$

Take values in  $\{\boxed{>}, \boxed{<}, \boxed{\approx}\}$



Random variables  $J_{p,q}^a$

Take values in  $\{\boxed{>}, \boxed{<}, \boxed{\approx}\}$

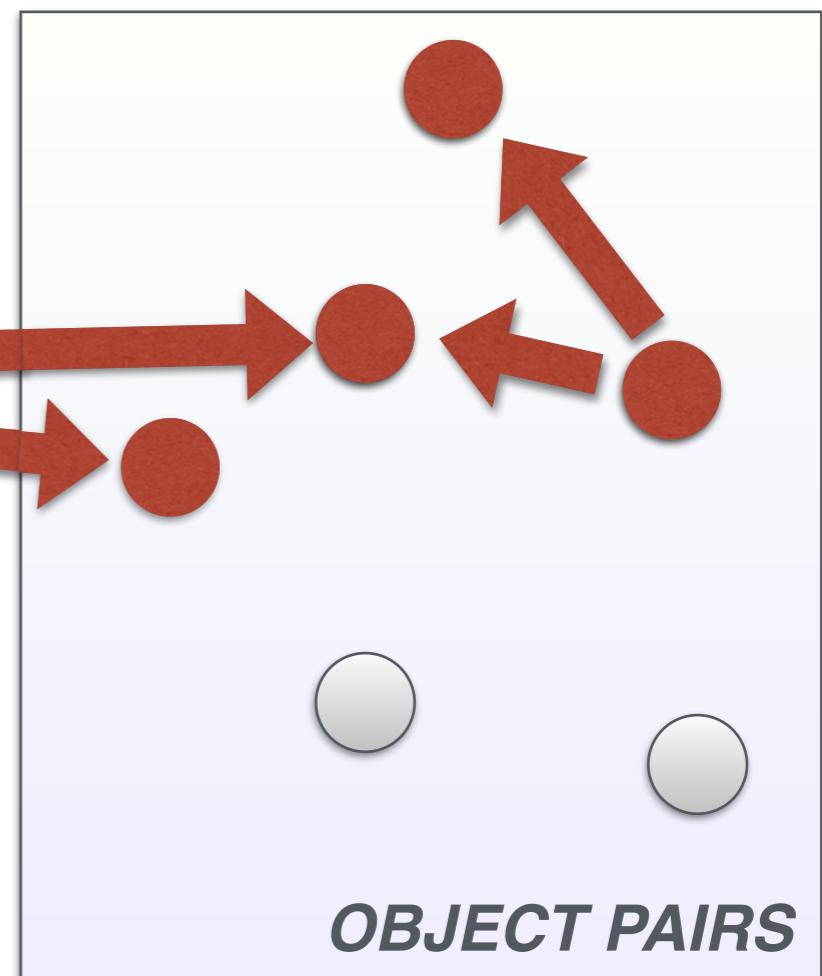
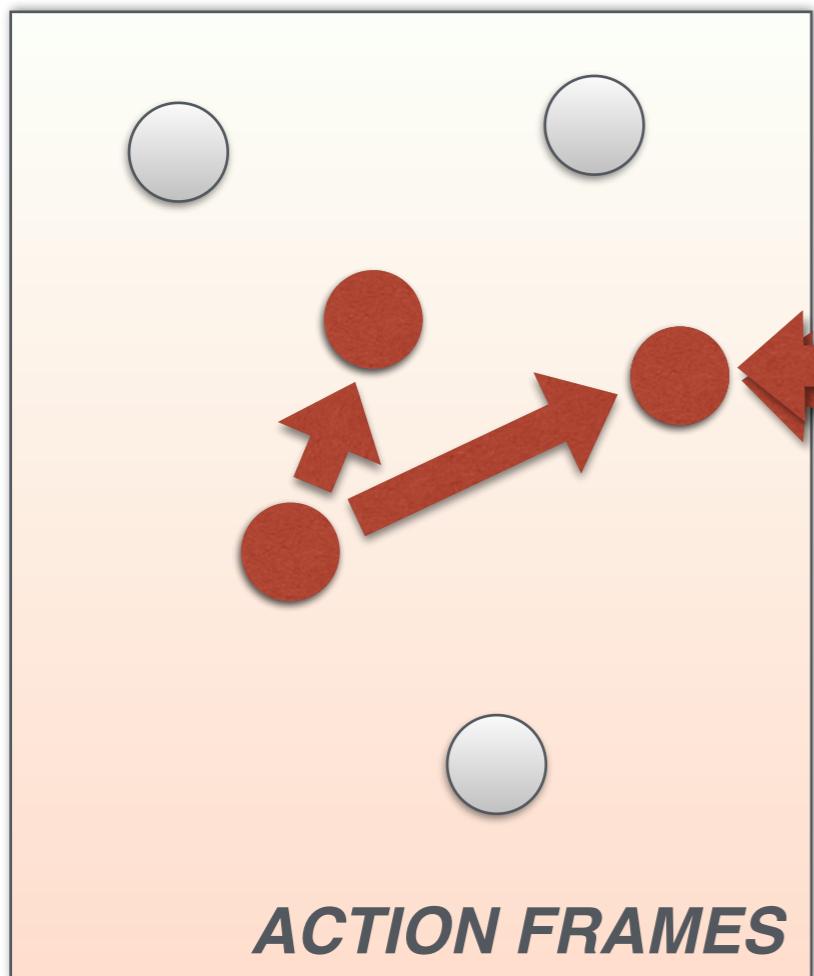


Random variables  $F_{v_t}^a$

Take values in  $\{\triangleright, \triangleleft, \approx\}$

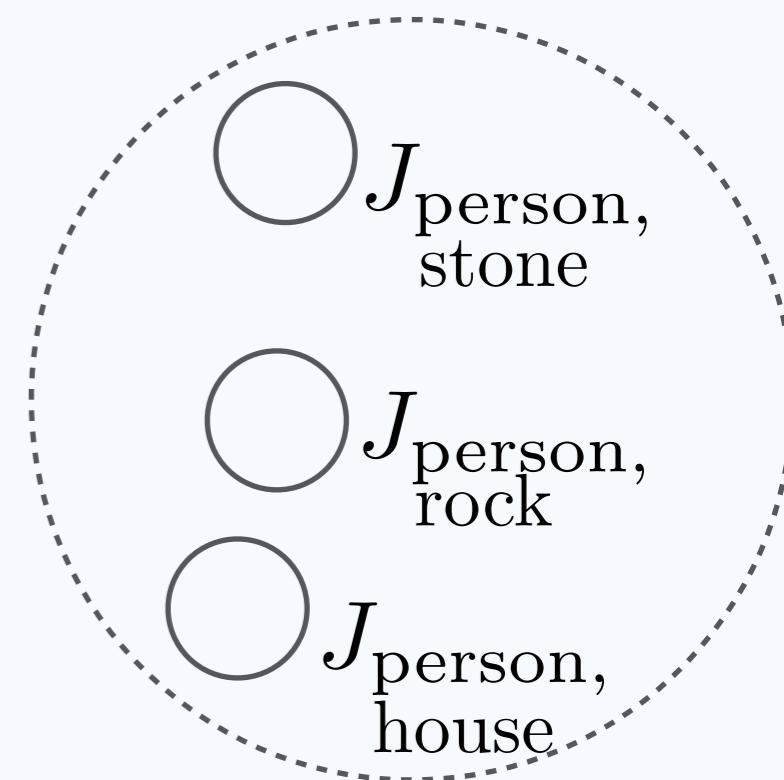
Random variables  $J_{p,q}^a$

Take values in  $\{\triangleright, \triangleleft, \approx\}$



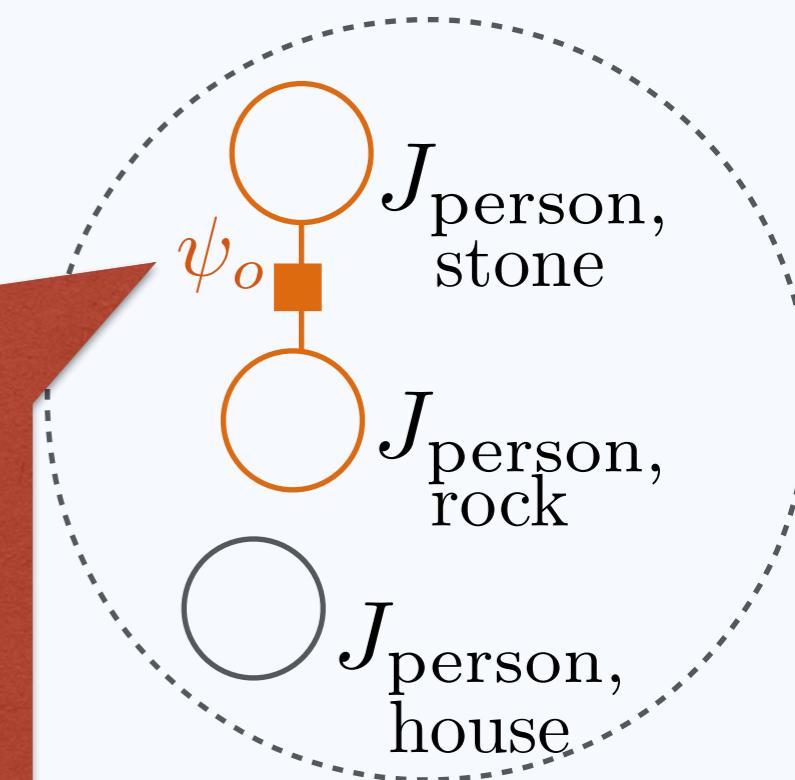
Size

## Object pair random variables



size

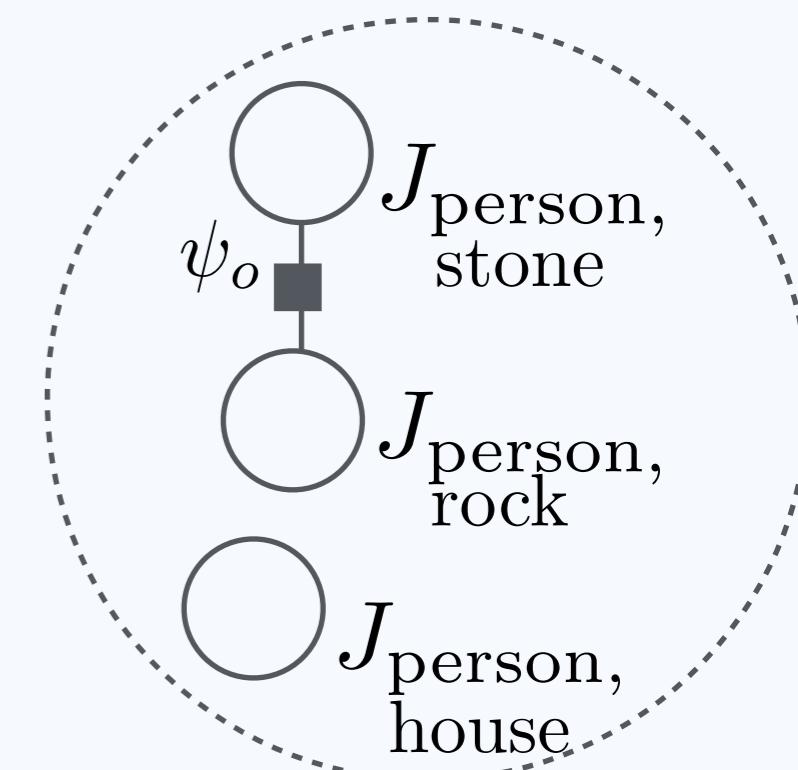
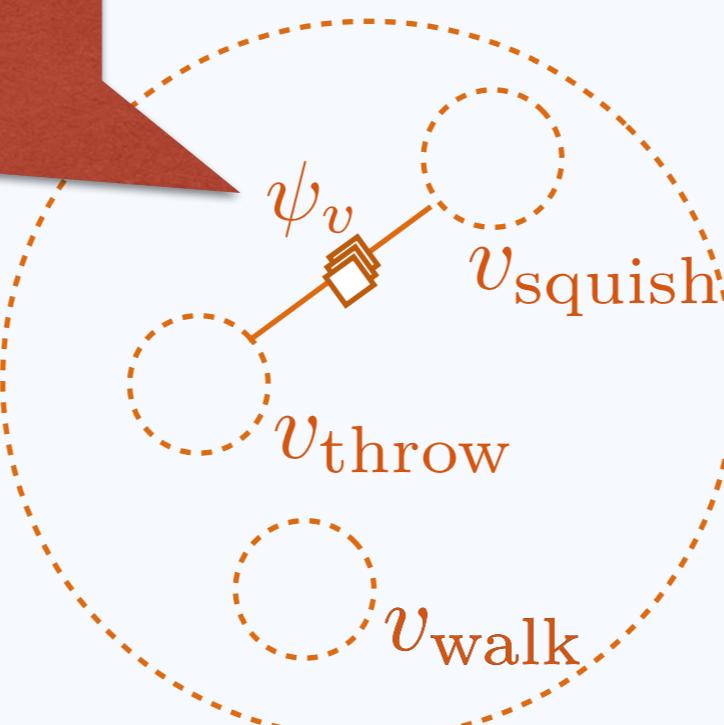
## Object similarity binary factors



# Verb similarity binary factors

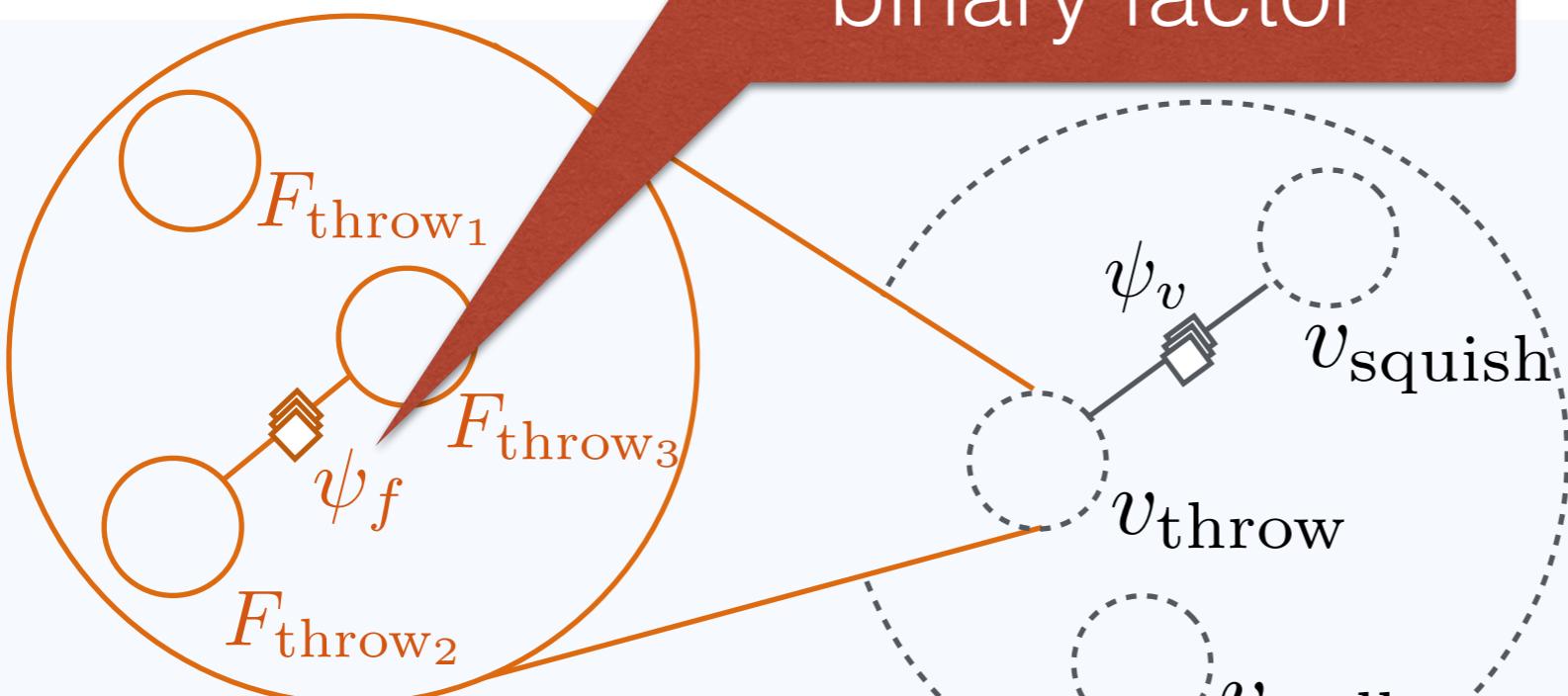
size

Action frames  
grouped by **verb**

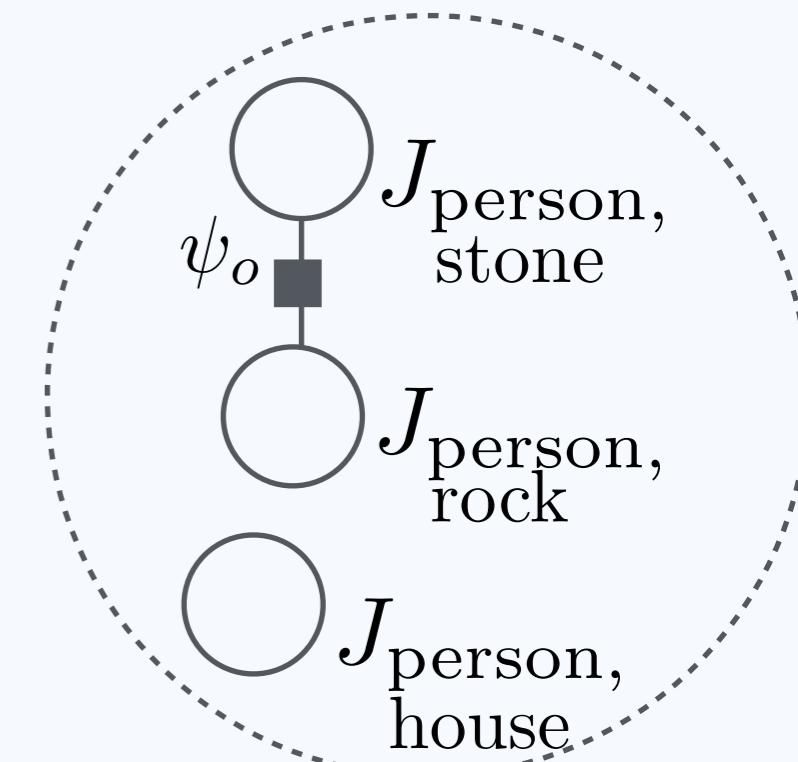


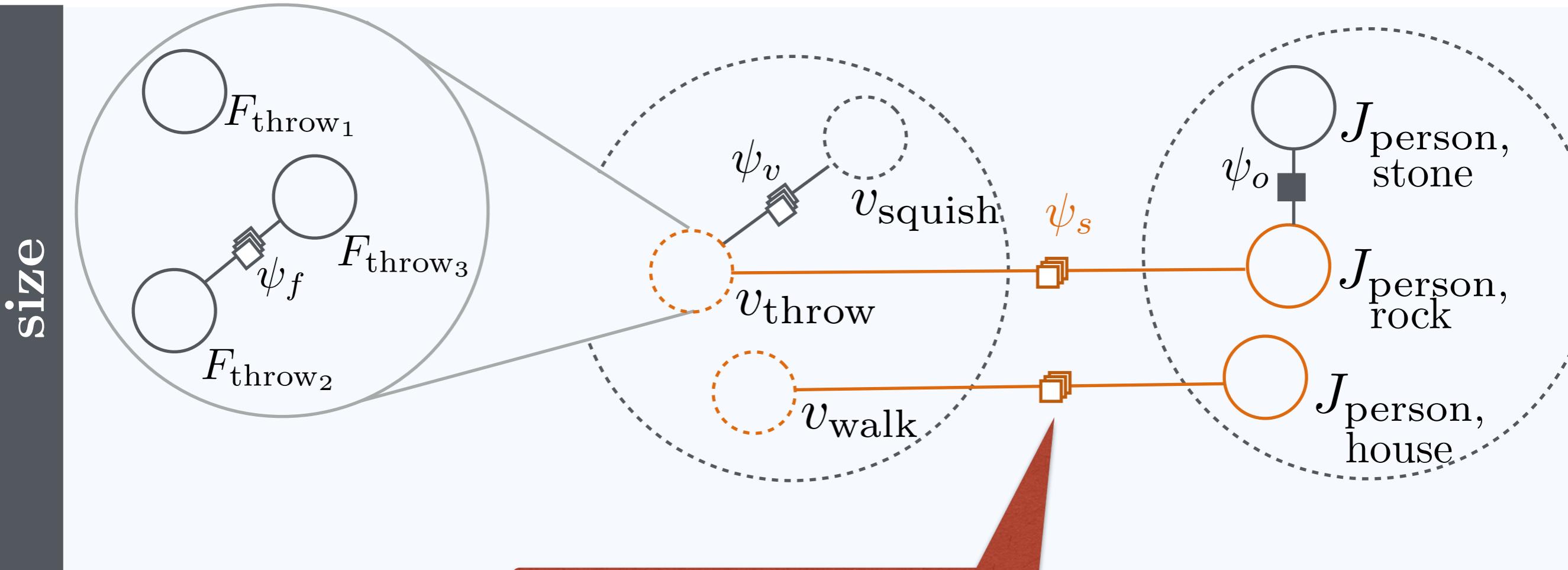
Similar frame  
construction  
binary factor

size



Several  
**action frames**  
per verb

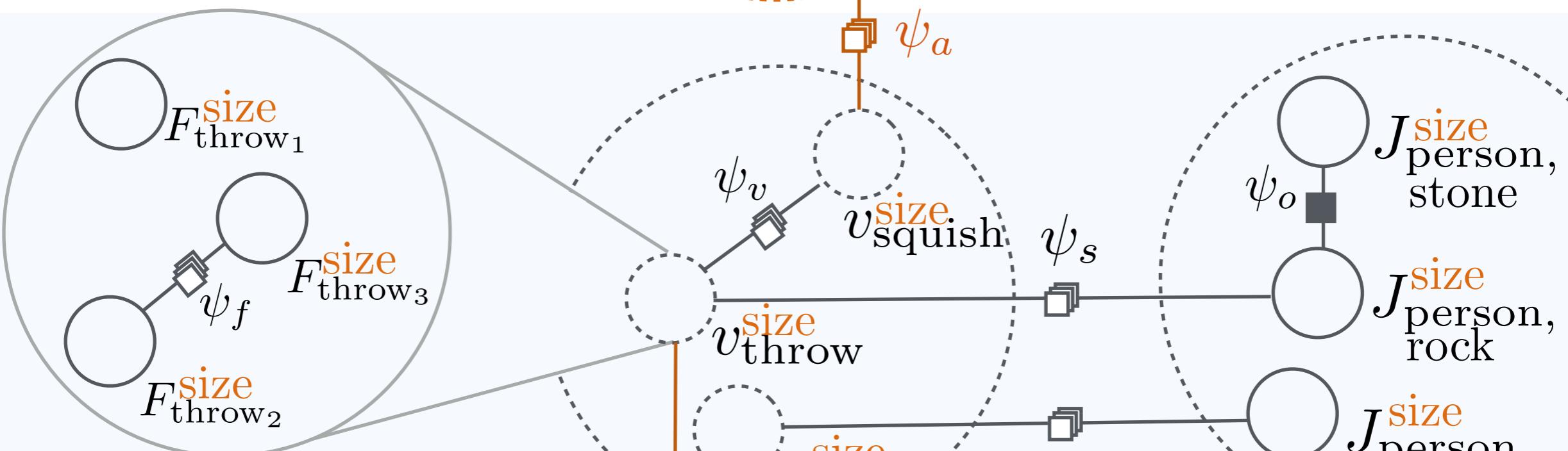




Action-object  
compatibility  
binary factors

strength

## More attributes

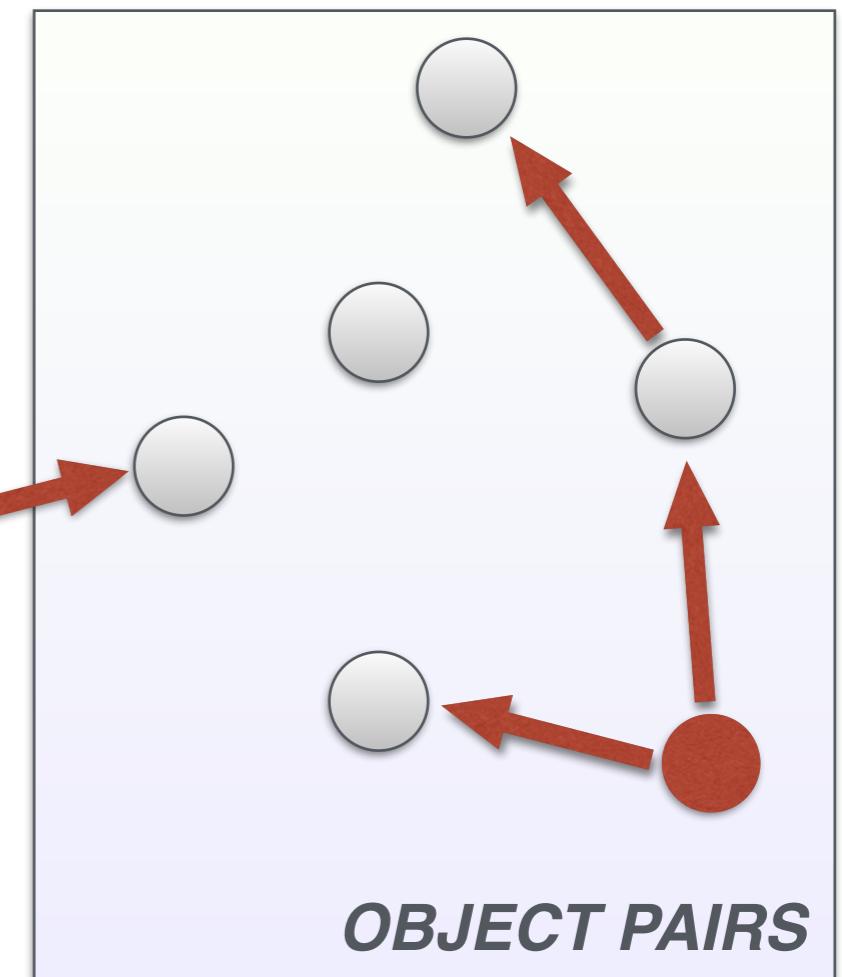
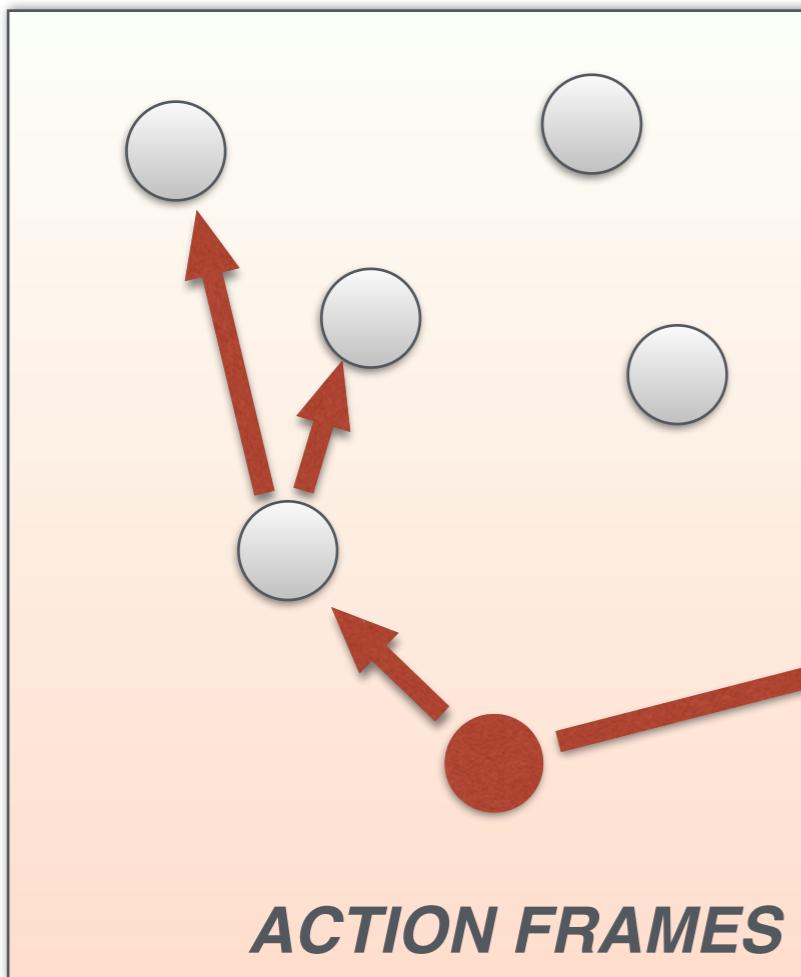
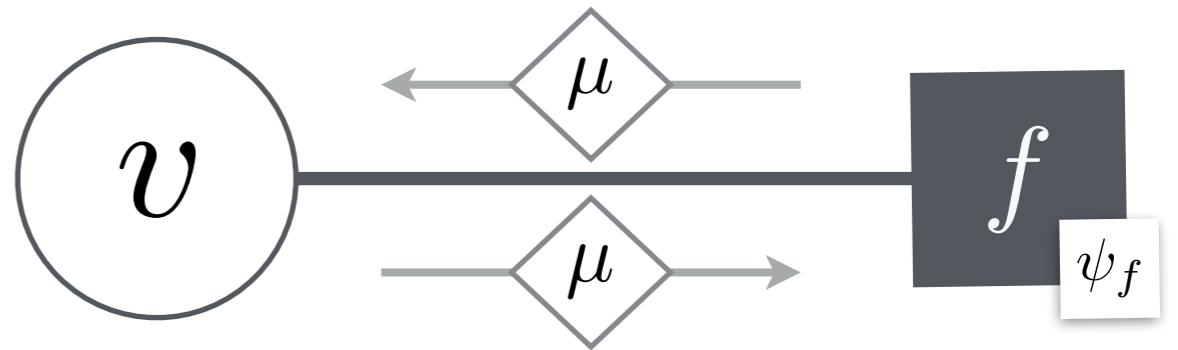


size

## Similar attribute binary factors

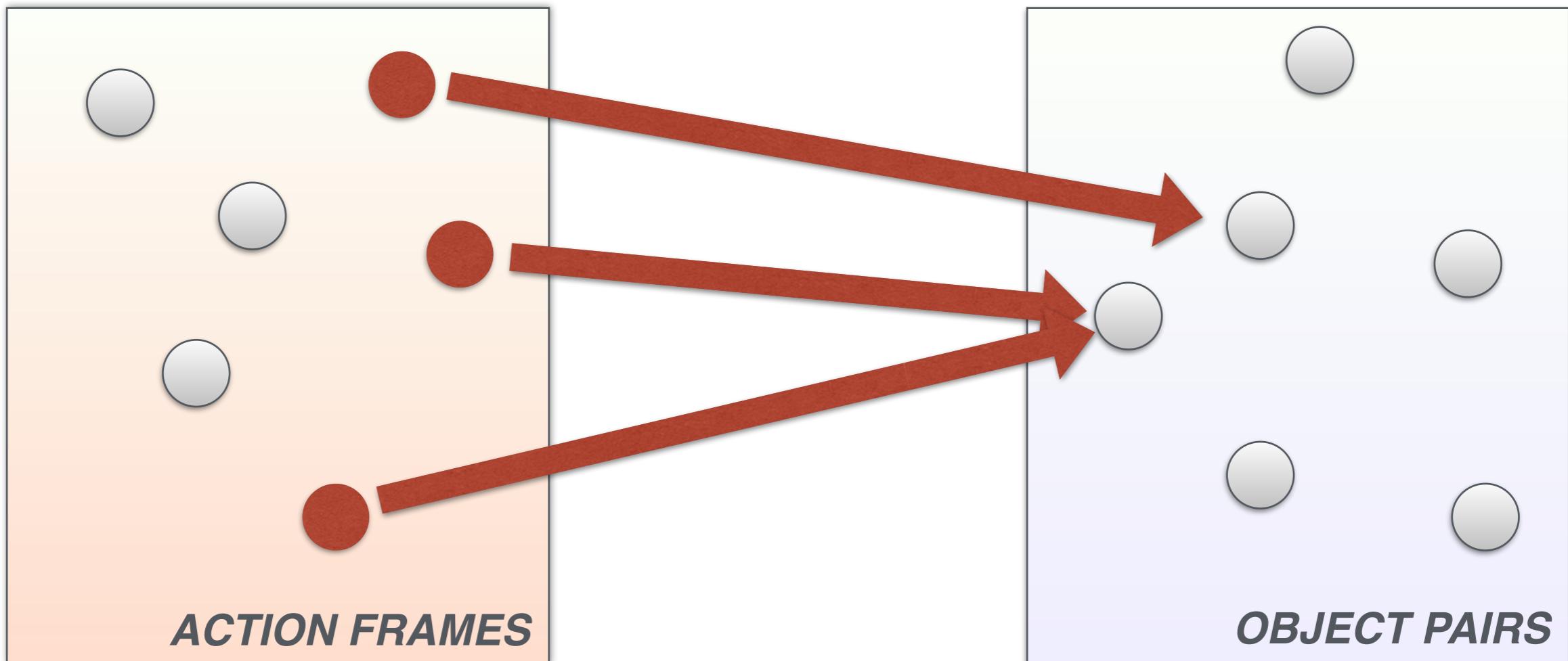
weight

# Loopy belief propagation

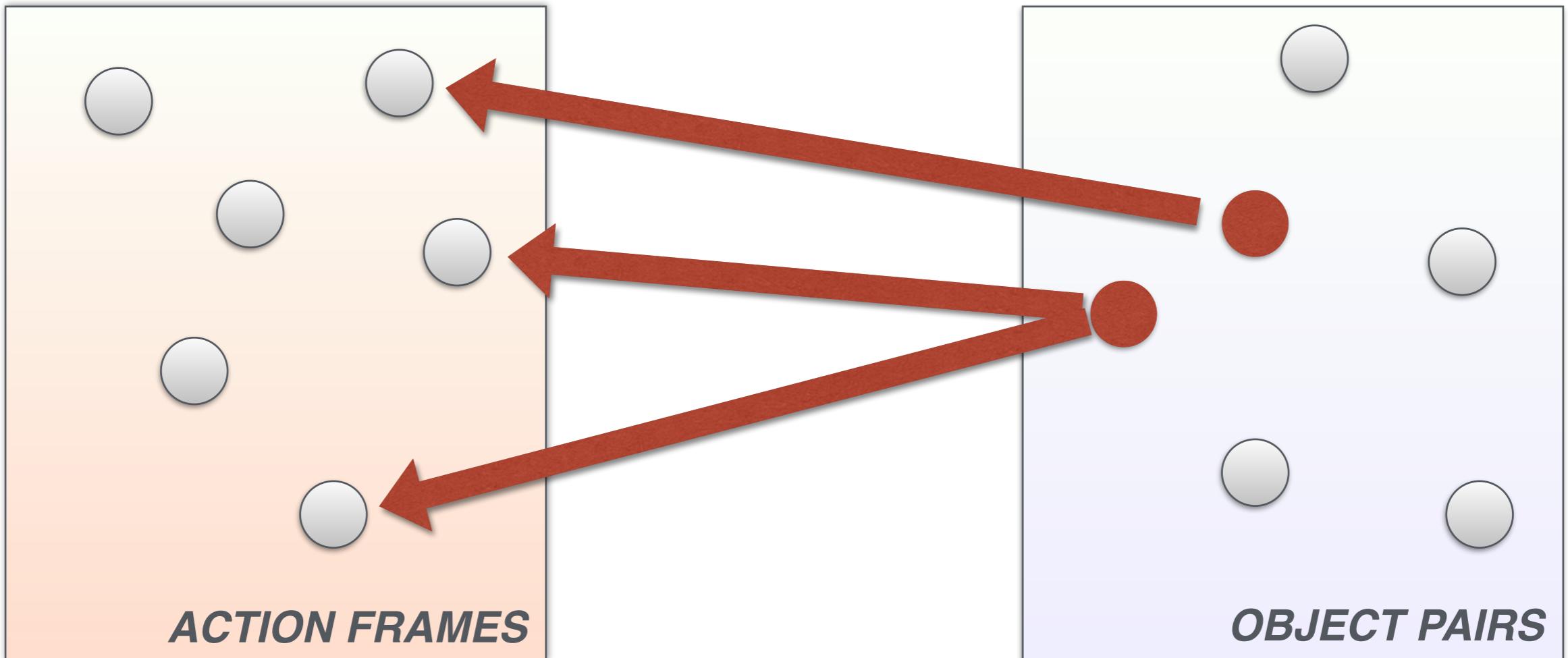


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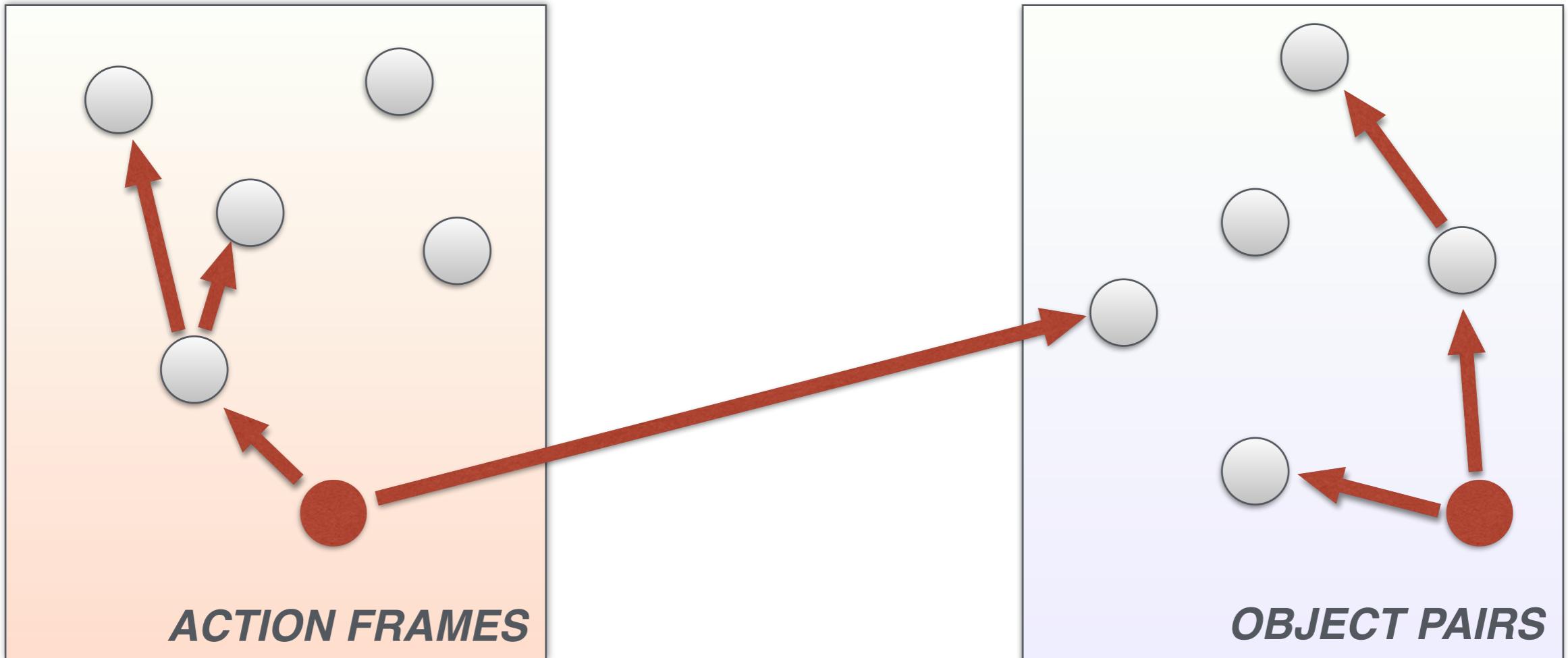
# Why collect data?



# Why collect data?



# Why collect data?



- Small **seed set** (5%) breaks symmetry
- **Evaluate** generalizability (dev = 45%, test = 50%)

# Selecting frames and objects

## Verbs

- took
- grew
- washed
- trimmed
- squished
- got
- looked
- wrote
- entered
- kept
- lived
- played
- ...

“Action” verbs

[Levin, 1993]

# Selecting frames and objects

## Verbs

- took
- grew
- washed
- trimmed
- squished
- got
- looked
- wrote
- entered
- kept
- lived
- played
- ...

## Action frames

- ...
  - $x$  squished  $y$
  - ~~$x$  squished on  $y$~~
  - PERSON squished  
 $x$  with  $y$
  - PERSON squished  
 $x$  on  $y$
- ...

Syntax + surface +  
crowdsourcing

# Selecting frames and objects

## Verbs

- took
- grew
- washed
- trimmed
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- got
- looked
- wrote
- entered
- kept
- lived
- played
- ...

## Action frames

- ...
- $x$  squished  $y$
- ~~$x$  squished on  $y$~~
- PERSON squished  $x$  with  $y$
- PERSON squished  $x$  on  $y$
- ...

## Object pairs

- ...
- spider, boot
- spider, glee
- ...

PMI > 0 on  
Google Syntax Ngrams

[Goldberg and Orwant, 1993]

not abstract via  
Wordnet

[Miller, 1995]

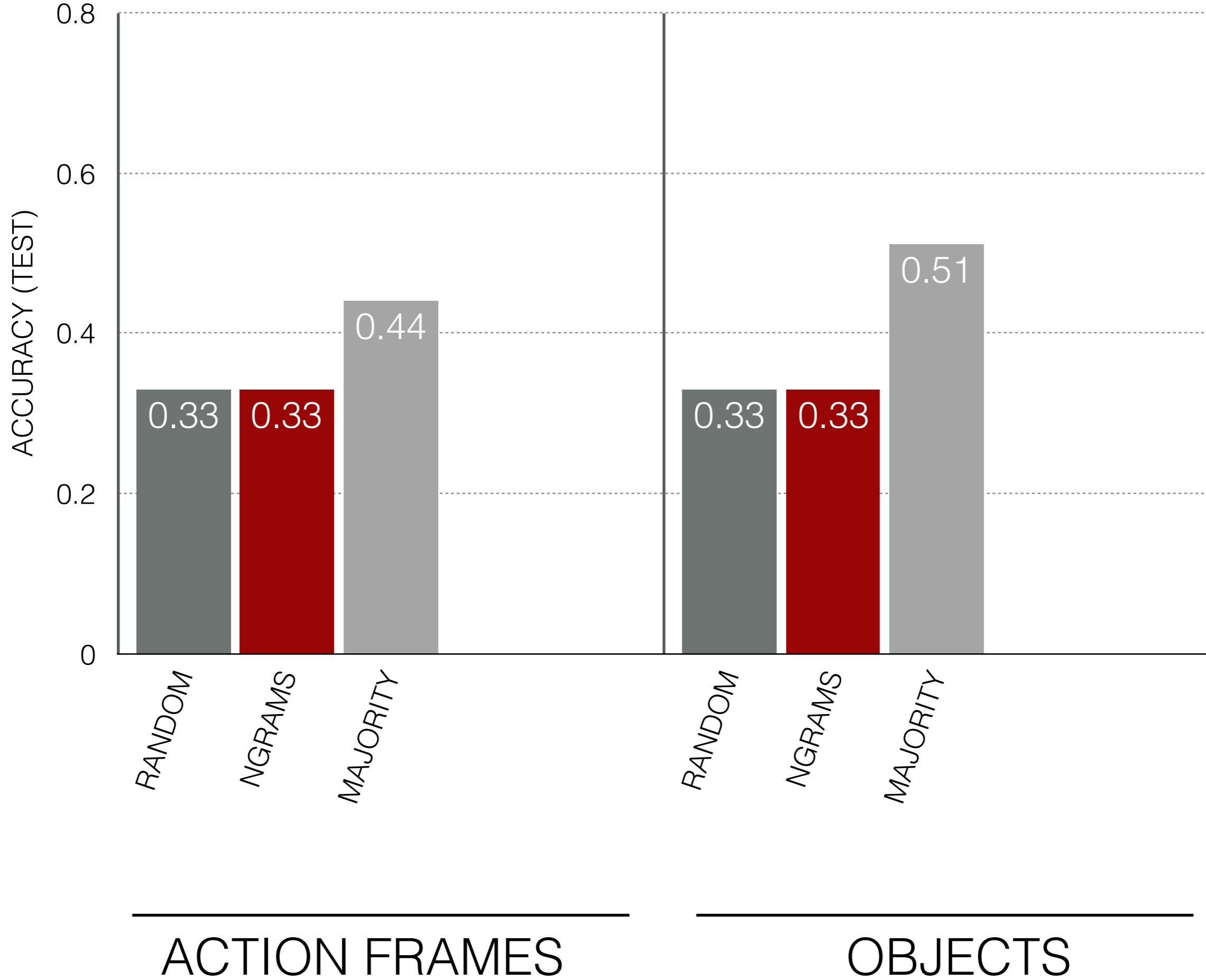
# Data statistics

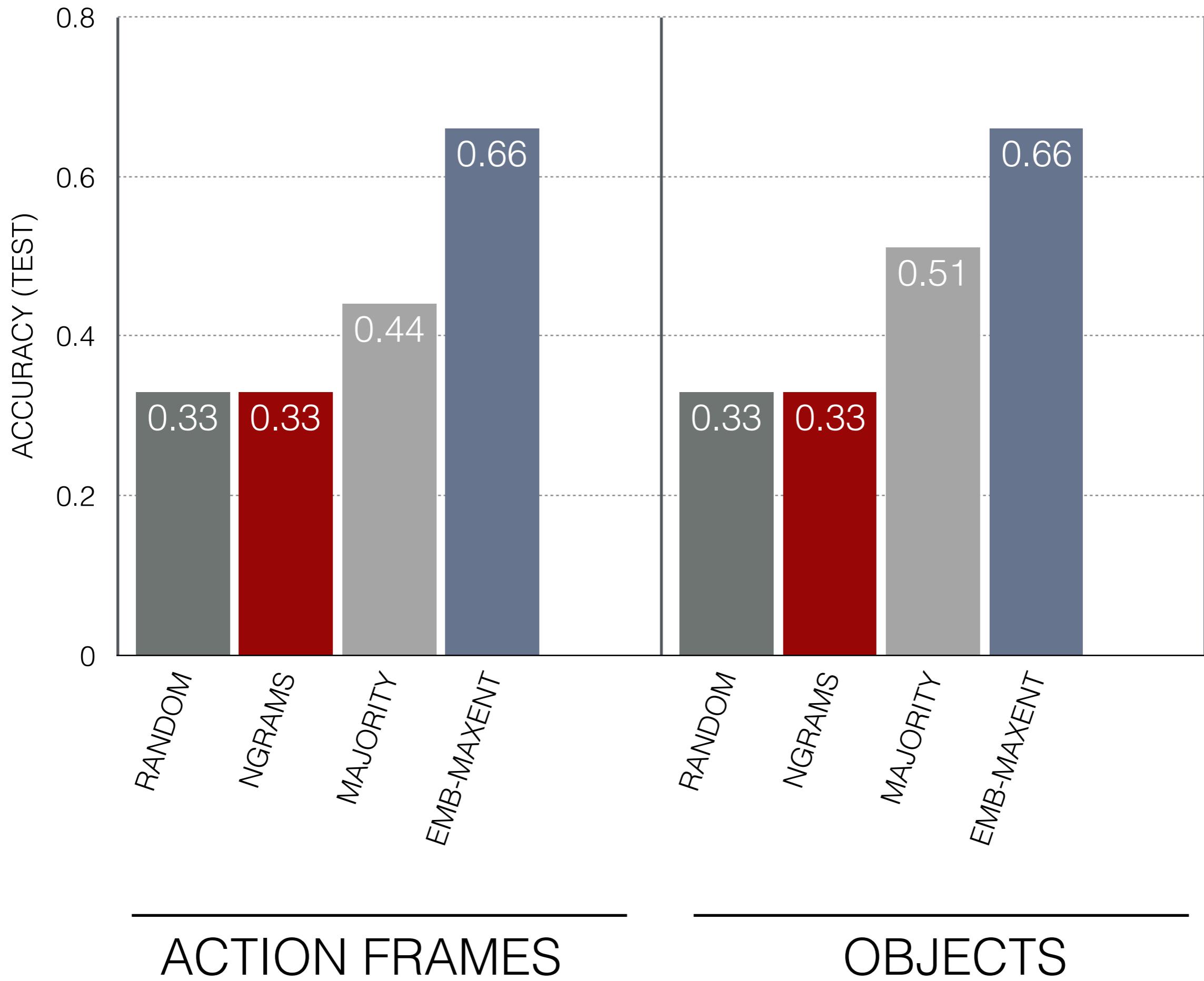
	Total
Verbs	100
Frames	813
Object pairs	3656

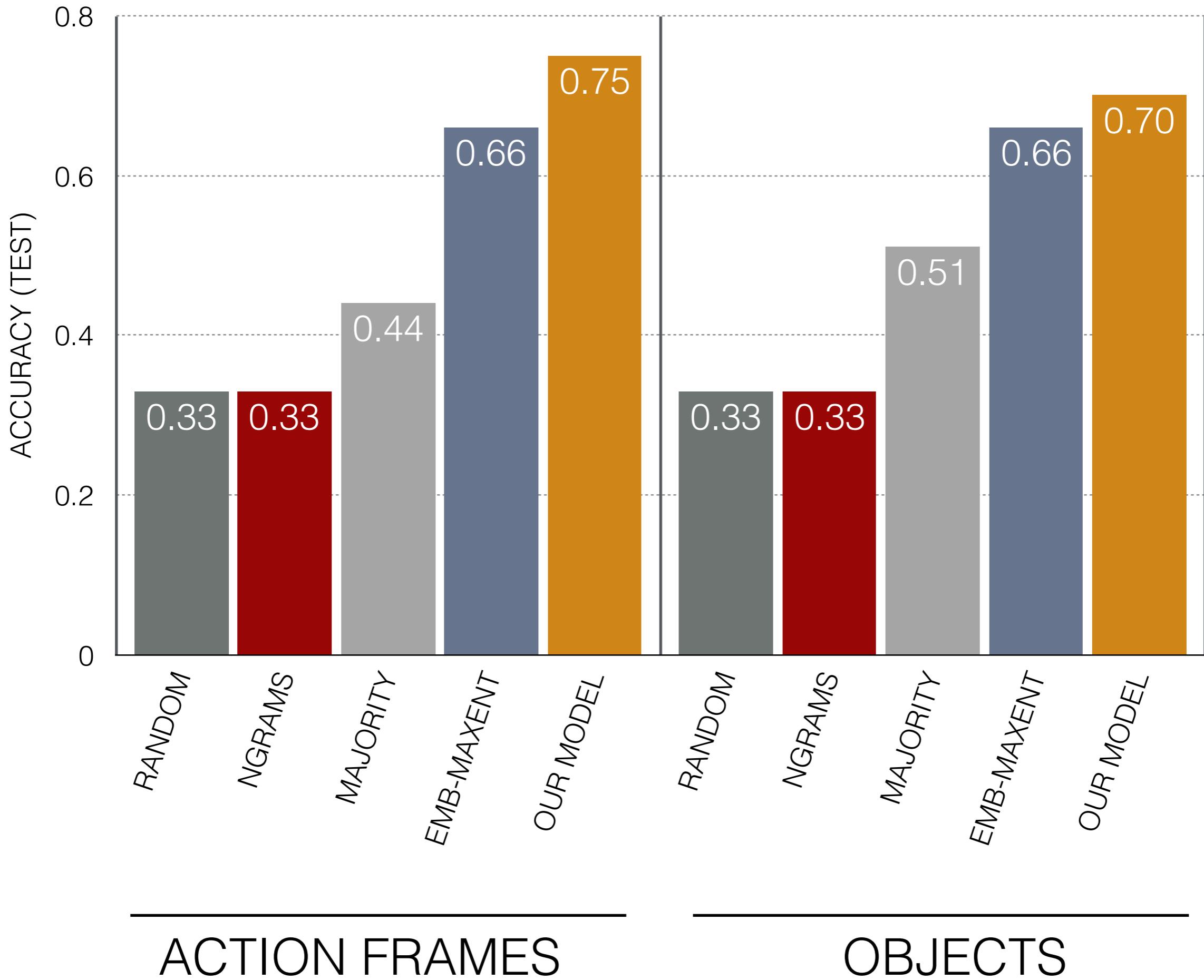
~8 action  
frames / verb

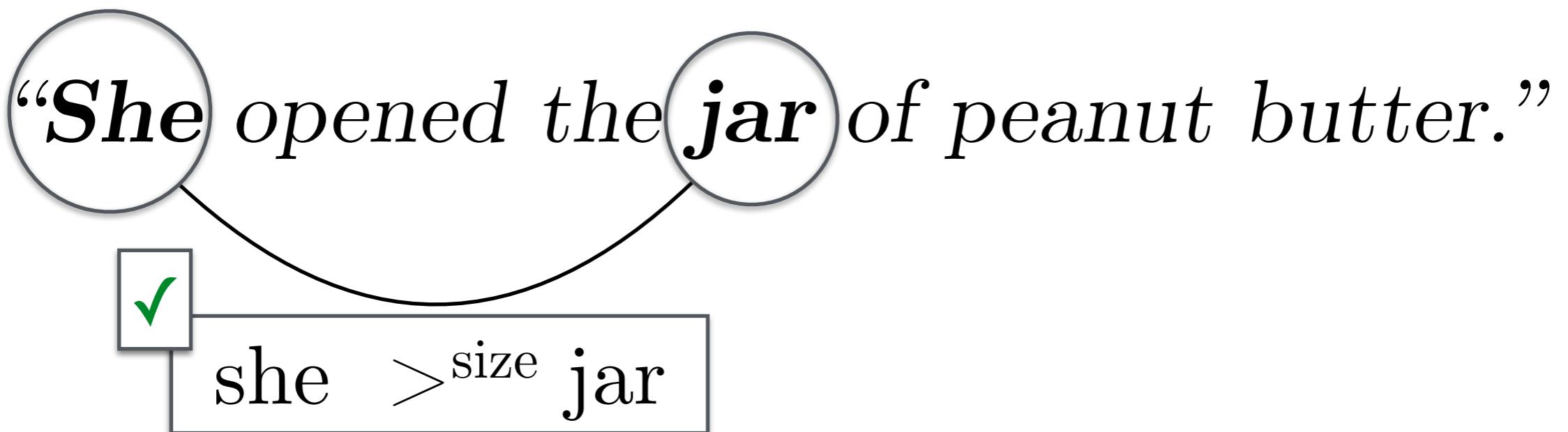
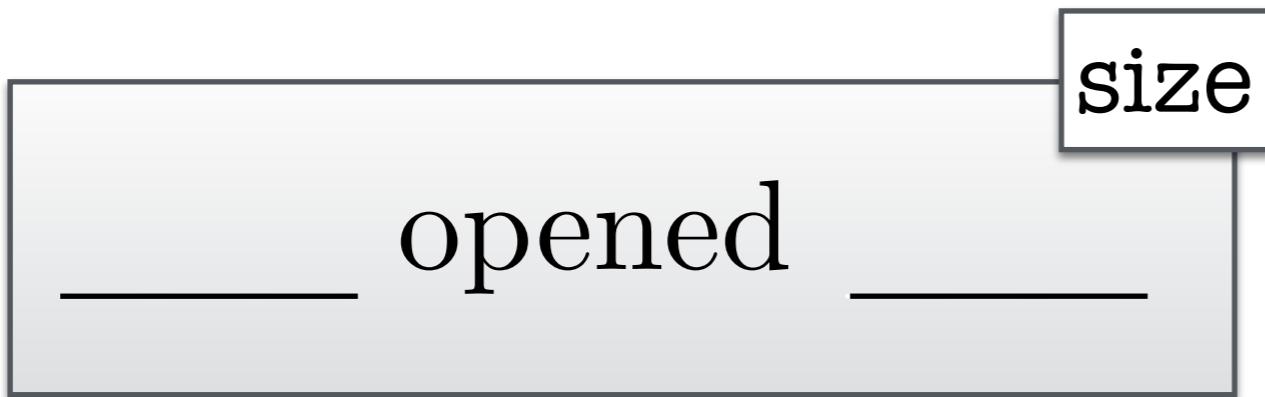
~200 distinct  
objects

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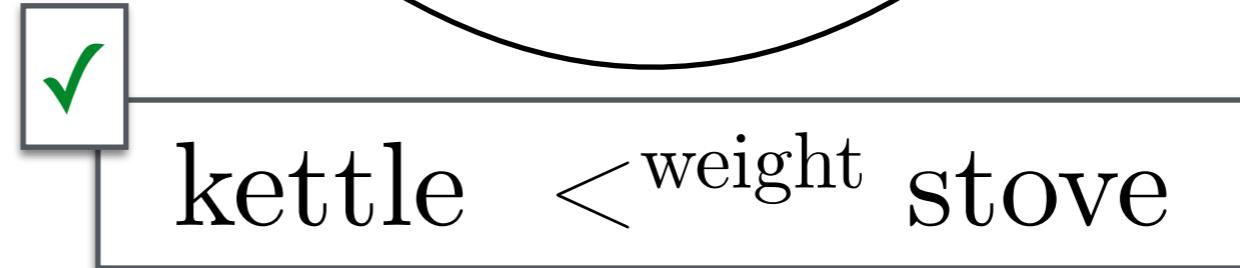


Correct dev set examples

PERSON set \_\_\_\_\_ upon \_\_\_\_\_

weight

“He set the **kettle** upon the **stove**.”



Correct dev set examples

speed

caught

our model

she ><sup>speed</sup> runner

– “**She** caught the **runner** in first.”

– “**She** caught the **baseball**.”

ground truth

she <<sup>speed</sup> baseball

polysemy

**Incorrect** dev set examples

PERSON stopped \_\_\_\_\_ with \_\_\_\_\_

weight

- “He stopped a **fly** with a **jar**.”
- “She stopped the **car** with the **brake**.”

our model

fly <weight jar

ground truth

car >weight brake

complex  
physics

*Incorrect dev set examples*

# Summary

- Reverse engineer  
**commonsense physical knowledge**
- Overcome **reporting bias** by modeling frames and objects



Max Forbes



Yejin Choi

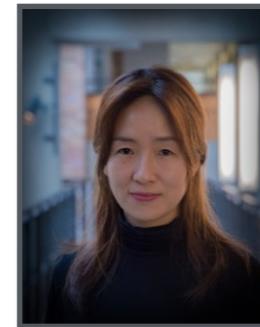
{mbforbes,yejin}@cs.uw.edu

# Summary

- Reverse engineer  
**commonsense**  
**physical knowledge**
- Overcome **reporting bias** by modeling frames and objects
- New dataset VERBPHYSICS  
[uwnlp.github.io/verbphysics/](https://uwnlp.github.io/verbphysics/)



Max Forbes



Yejin Choi

{mbforbes, yejin}@cs.uw.edu

