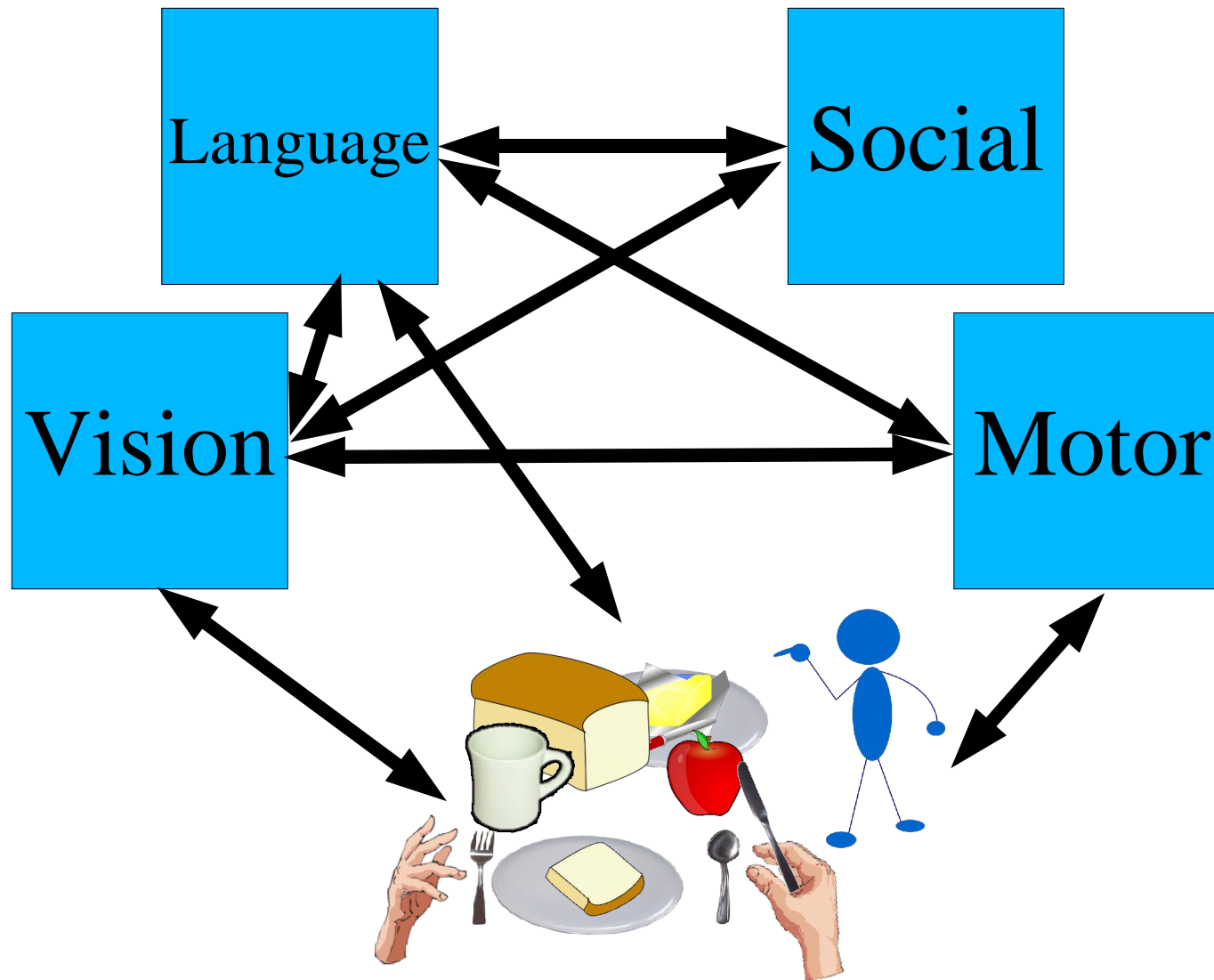


Leveraging Language into Learning

Jake Beal
MIT CSAIL
AAAI-DC 2005

When parts learn to work together...

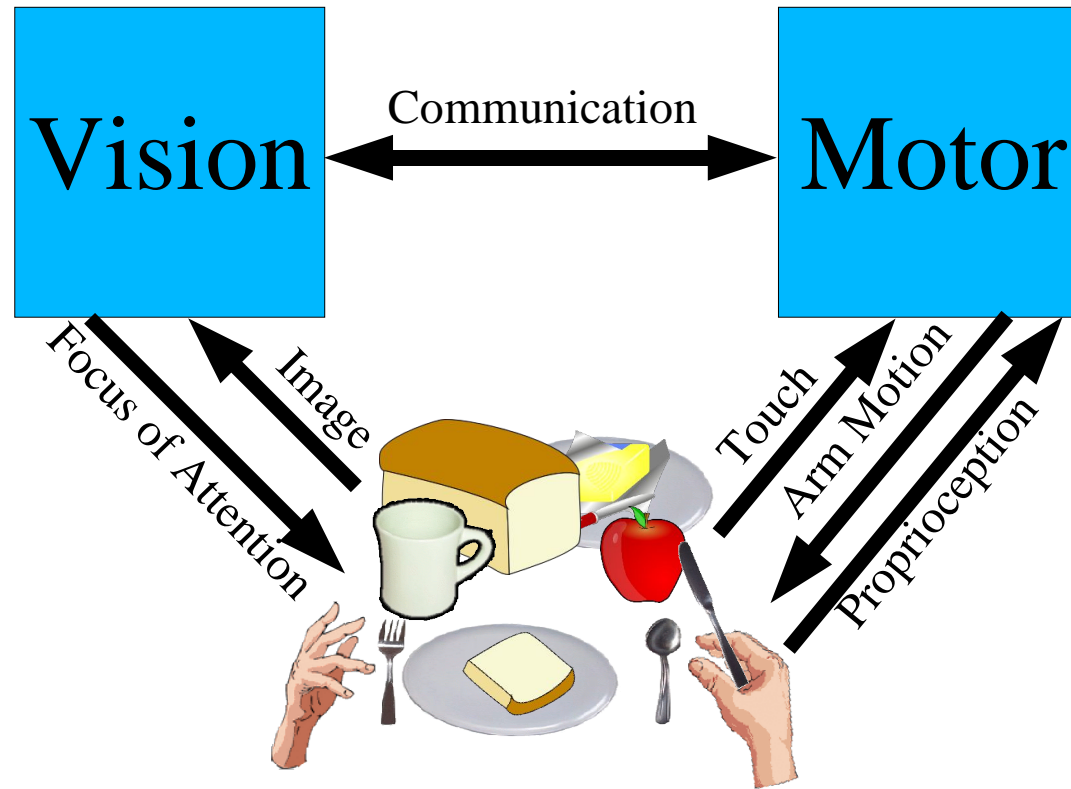


Hypothesis

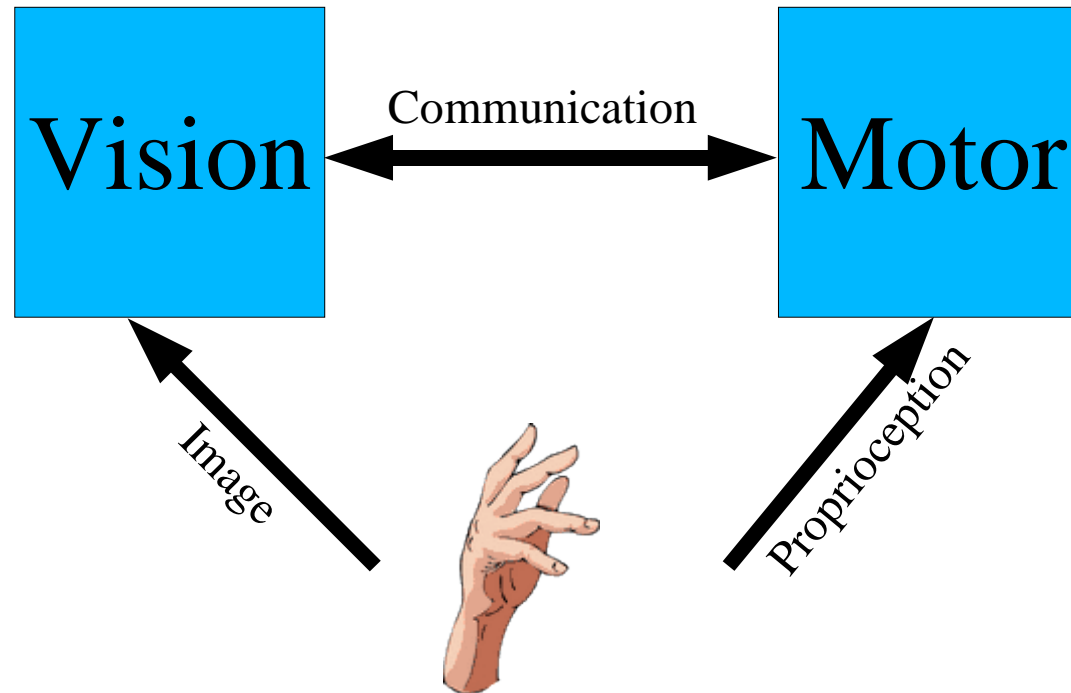
- When individuals learn to communicate, it teaches the group about the world.

i.e. learning hand-eye coordination teaches about cutting, throwing, gravity, etc...

Example: Hand-Eye Coordination

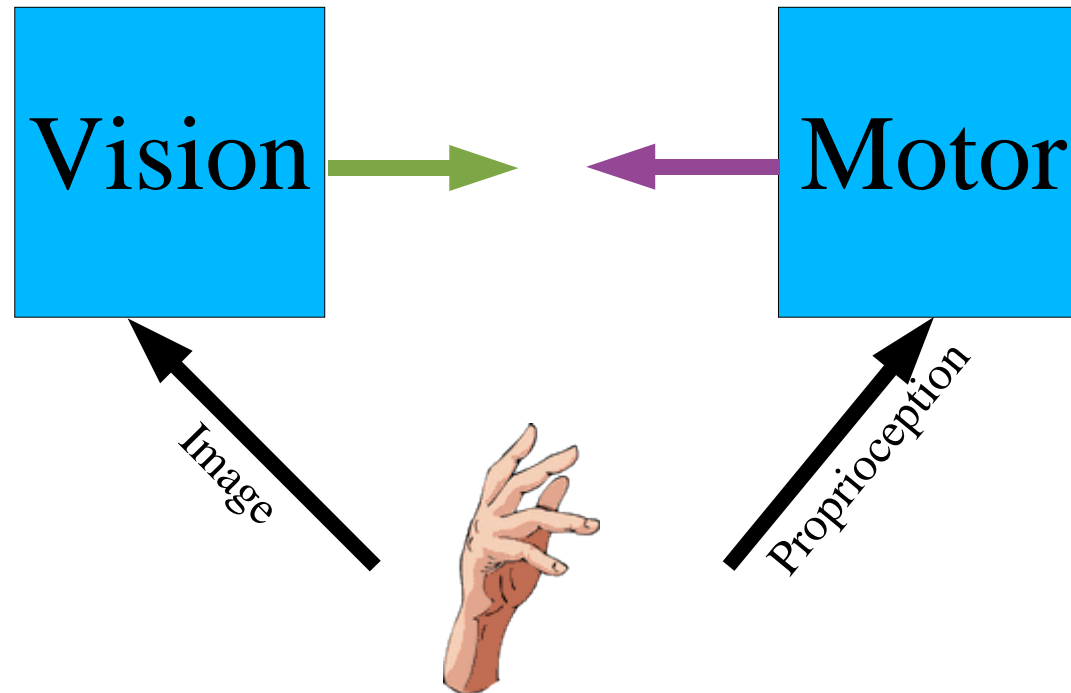


Shared Experiences → Vocabulary



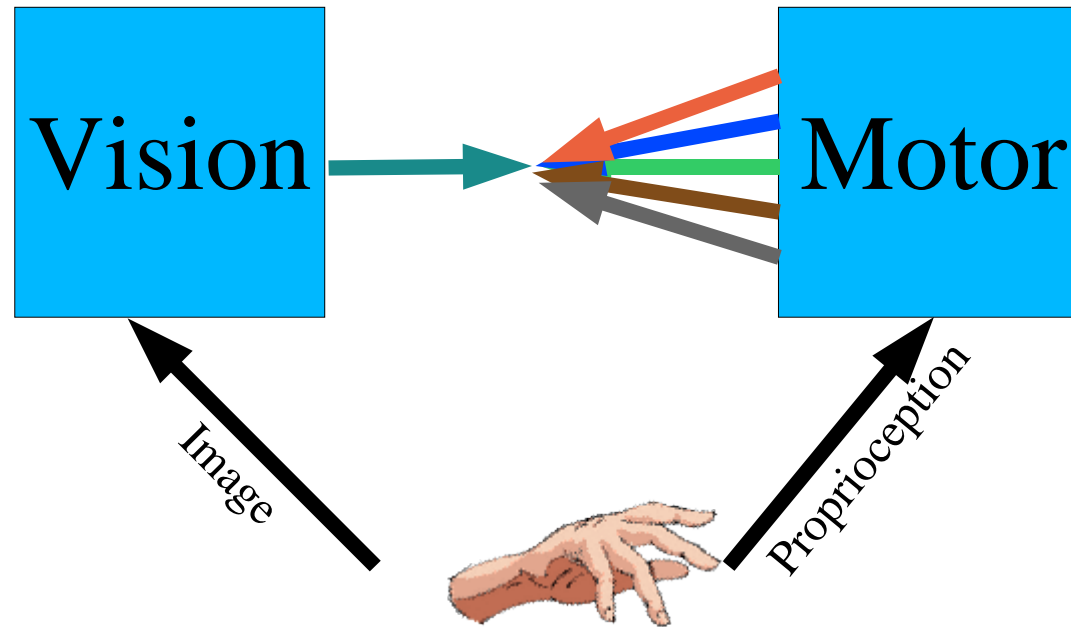
- Strong correspondence between
 - Arm & head position
 - Location of a pink blob in the visual field

Shared Experiences → Vocabulary



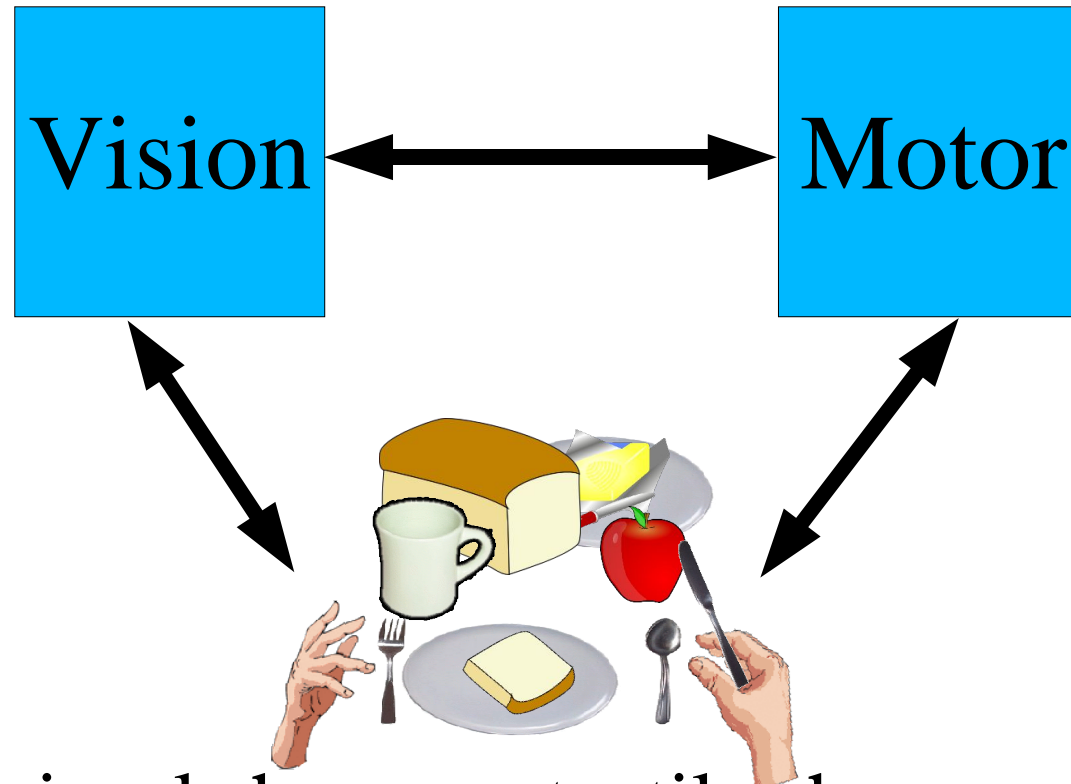
- Each module invents a “word” for the situation
 - Motor “word” matches one pink blob location
 - Vision “word” matches several arm/head positions

Shared Experiences → Vocabulary



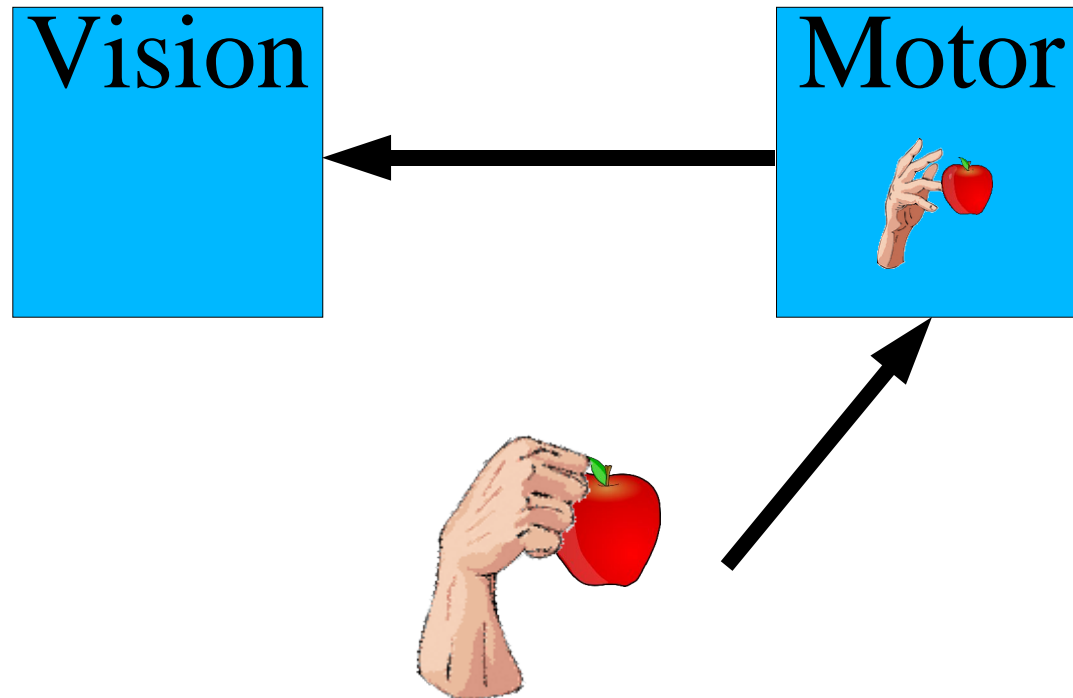
- Vision and motor “words” form a mapping between arm/head position and pink blob location

More Complicated Relations...



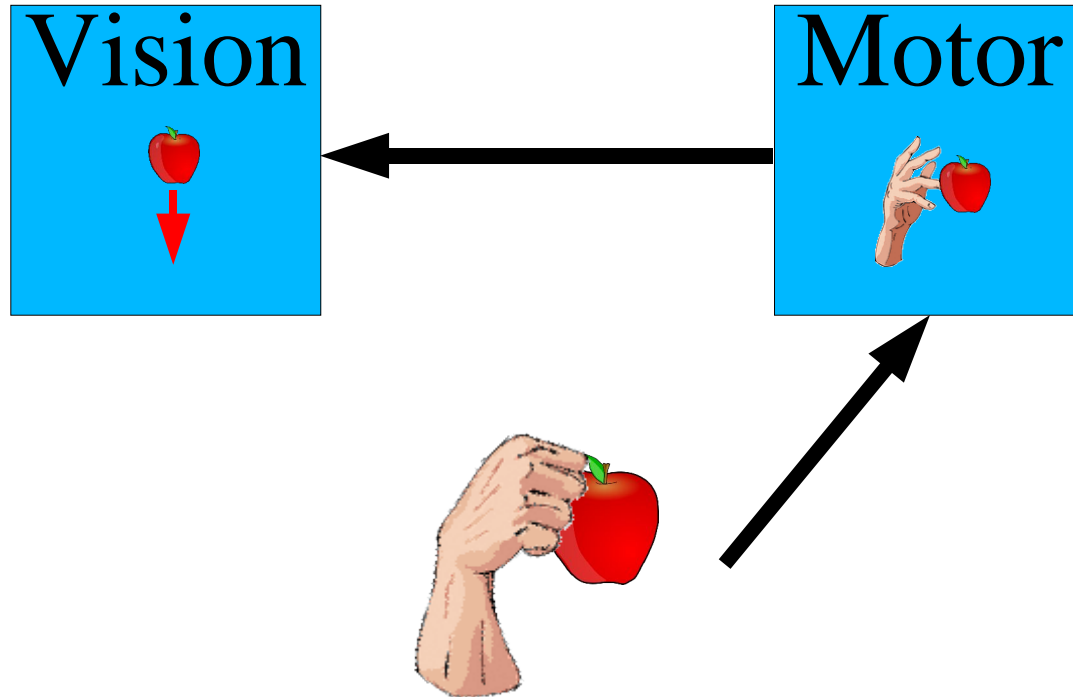
- Apple: visual shape \leftrightarrow tactile shape
- Utensil: visual shapes \leftrightarrow gripping motion
- Cut: shape splits into two \leftrightarrow sawing motion

Translation \rightarrow Reasoning



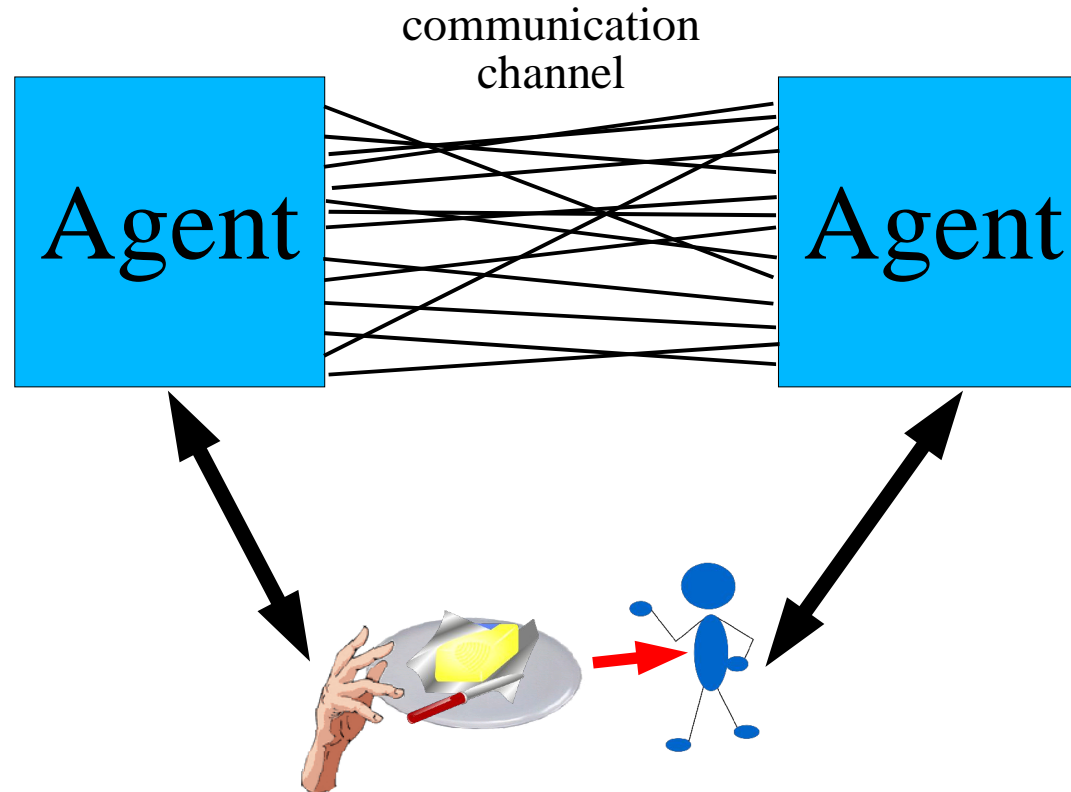
- Motor says “the apple is being released”

Translation → Reasoning



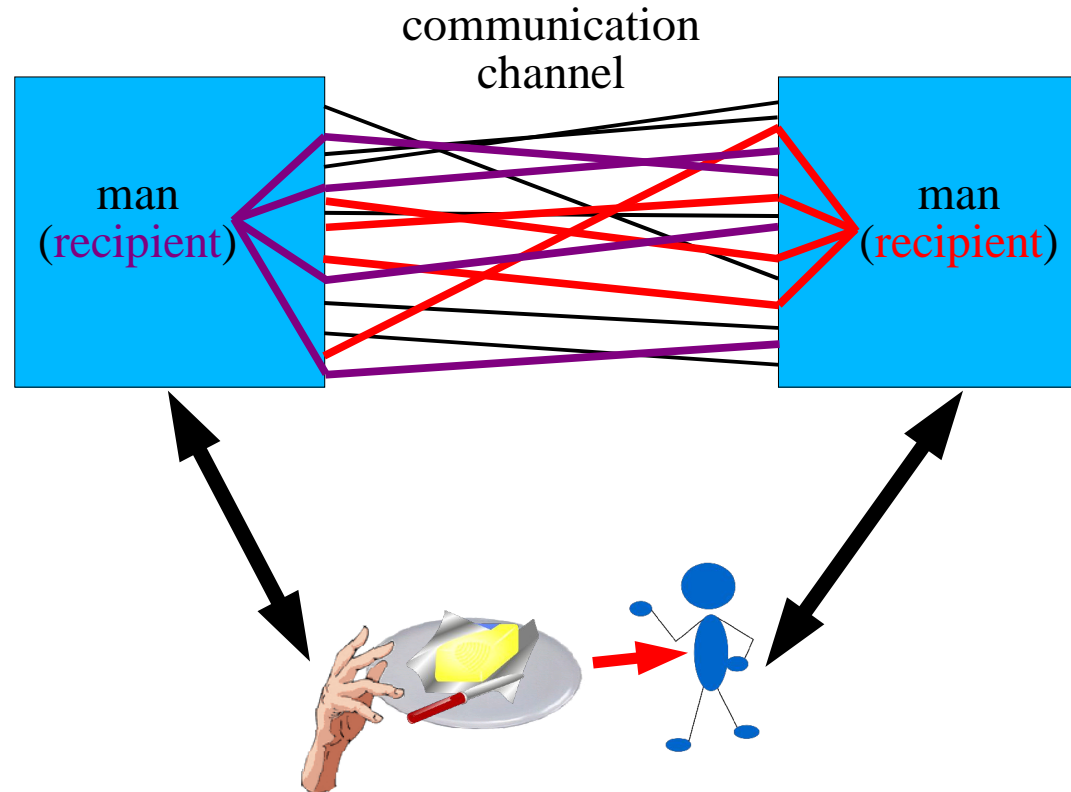
- Motor says “the apple is being released”
- Vision understands “the apple is falling”

Communication Bootstrapping



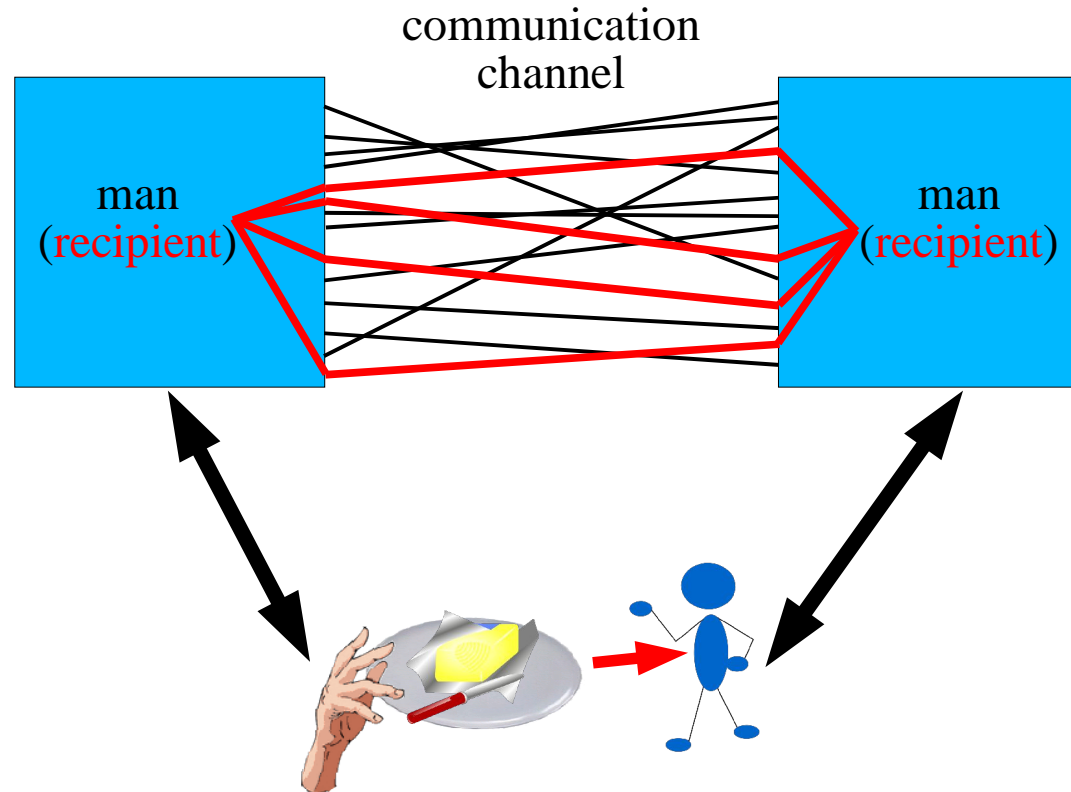
- Learning from shared experience
 - [inspired by Kirby, Yanco, Steels]
- Communication on a twisted bundle of wires

Communication Bootstrapping



- Each agent translates the scene into a personal encoding not initially understood by its partner
 - Symbols are random sparse encodings
 - Inflections indicating role are modulations

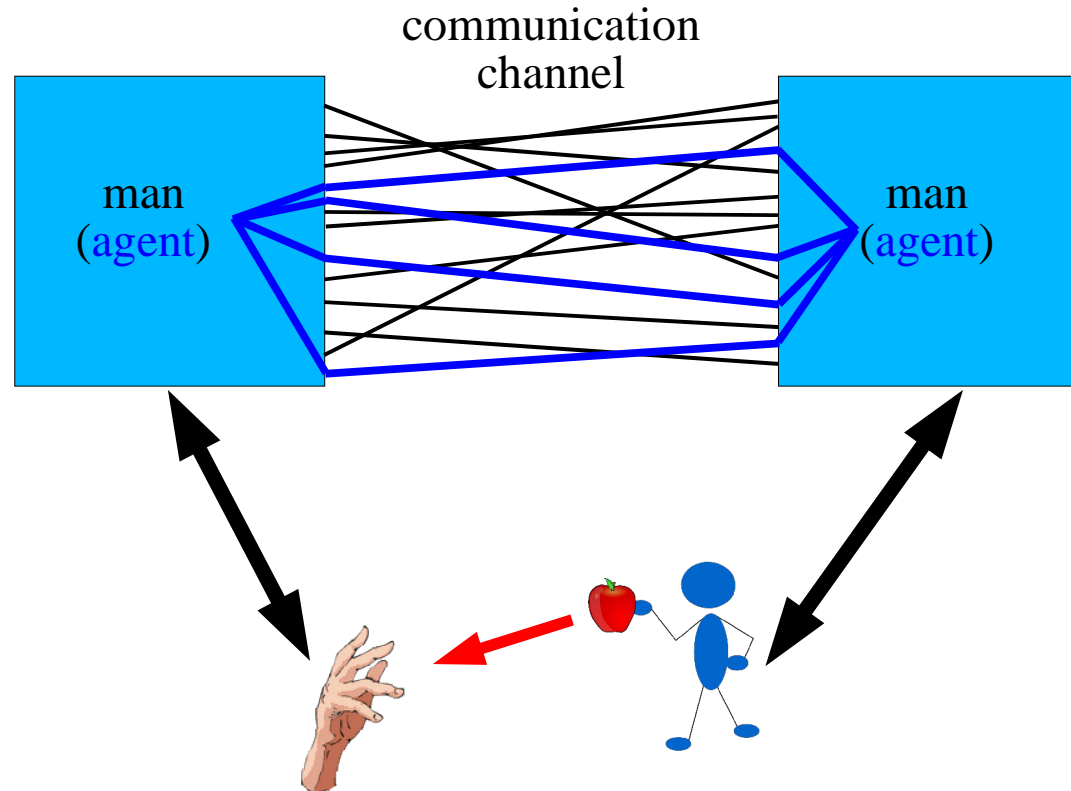
Communication Bootstrapping



Sparseness + shared observation = learnable correlations

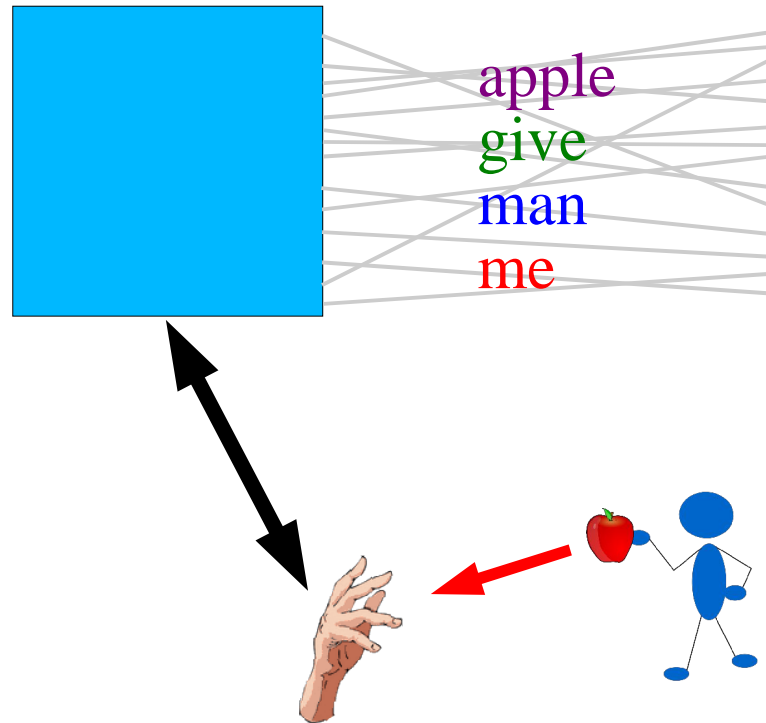
- Converges to equivalent vocabulary, inflections

Communication Bootstrapping



- Symbols + inflections = additive language
 - Composable into complex “sentences”
 - New symbols use existing inflections, and vice versa

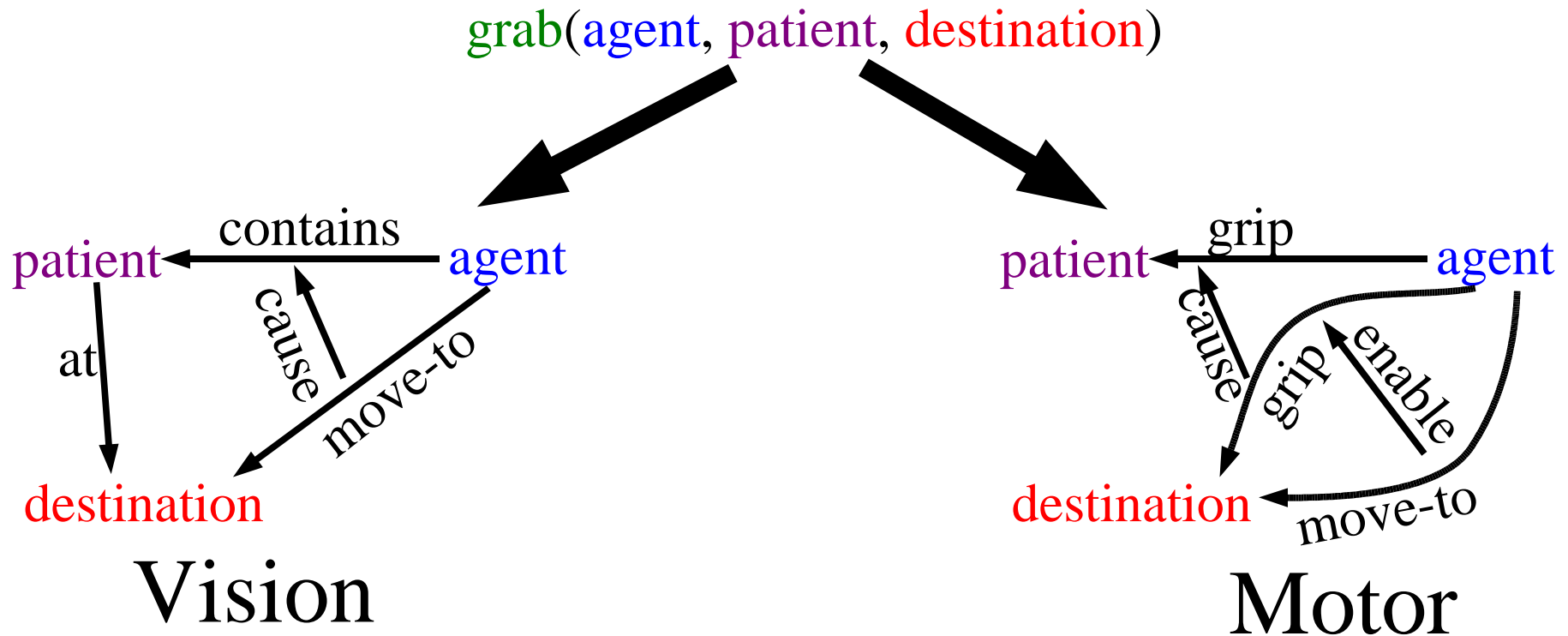
Inflections can act as variables



`give(agent, patient, recipient)`

- “Give” can be interpreted as a relation with three variables indicated by inflections.

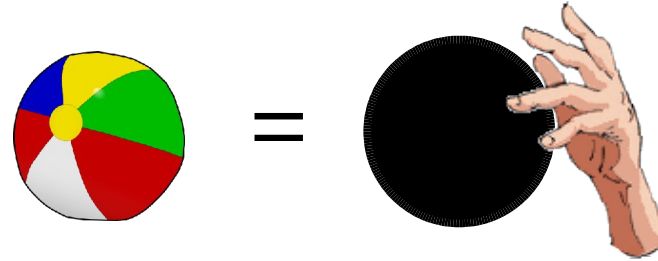
Symbols can act as abstractions



- Each agent interprets a relation as the projection of its structure into that agent's worldview.
- Inflections are points of coordination

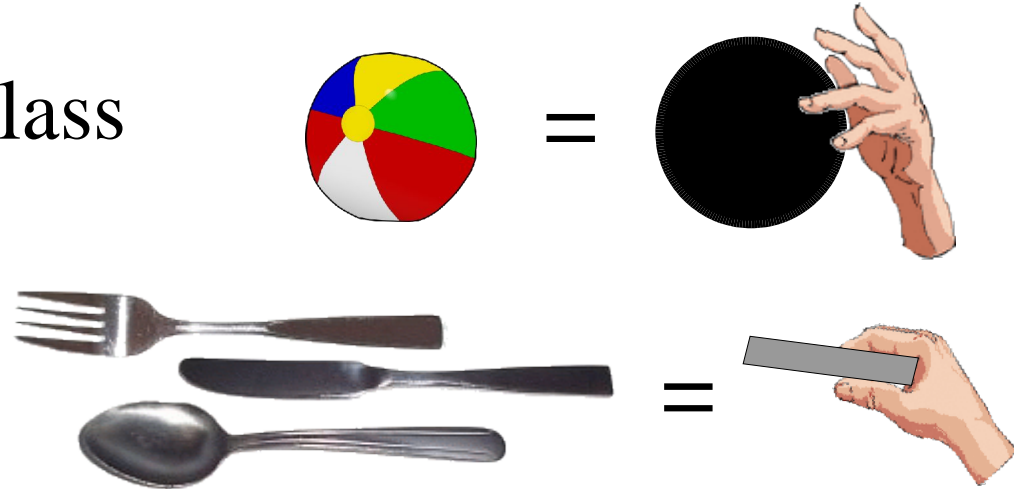
Learning Relations Besides Identity

- Part/Whole



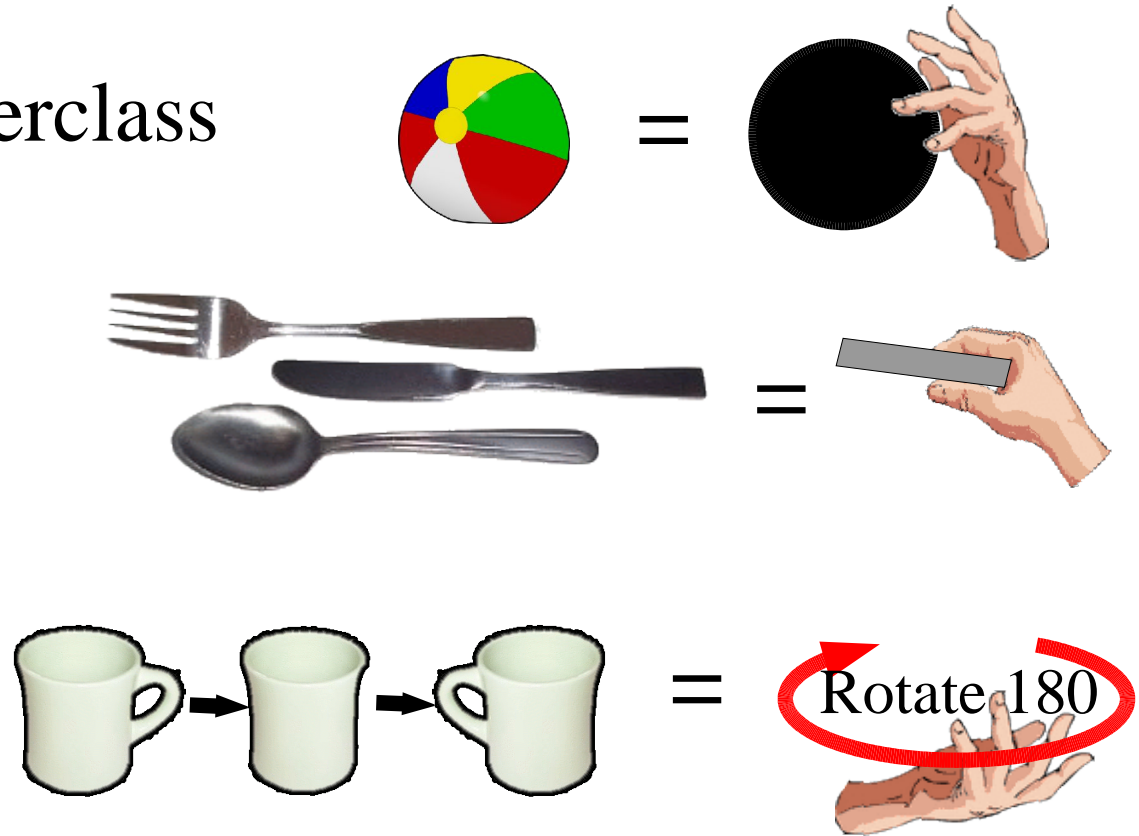
Learning Relations Besides Identity

- Part/Whole
- Subclass/Superclass



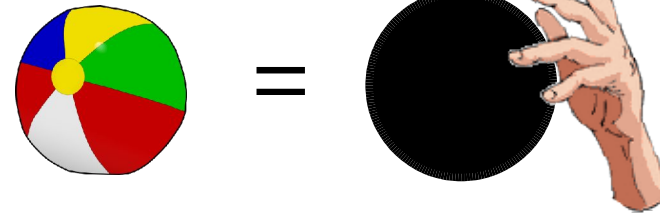
Learning Relations Besides Identity

- Part/Whole
- Subclass/Superclass
- Sequence



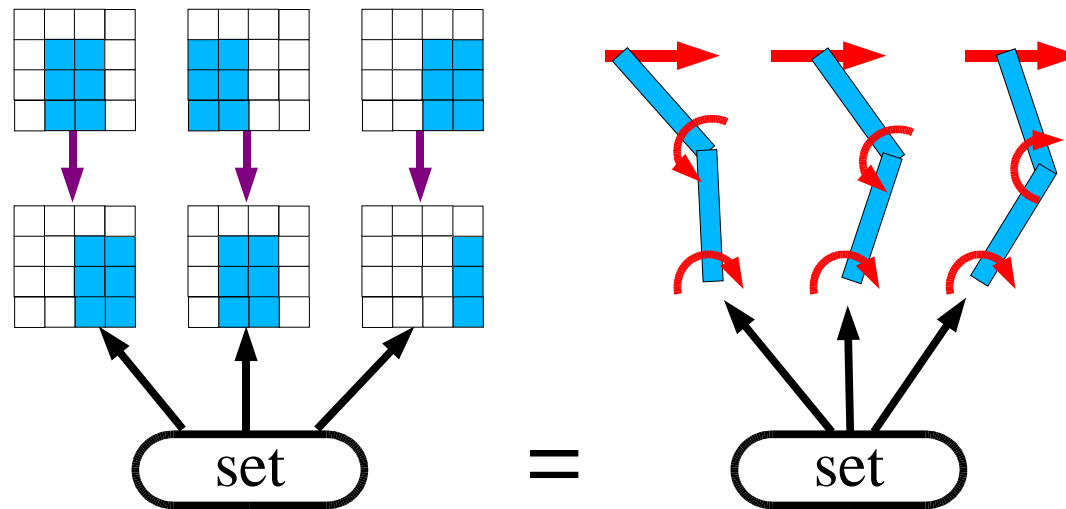
Learning Relations Besides Identity

- Part/Whole
- Subclass/Superclass
- Sequence
- Difference
- Container/Contained
- Causality
- Measure
- ...



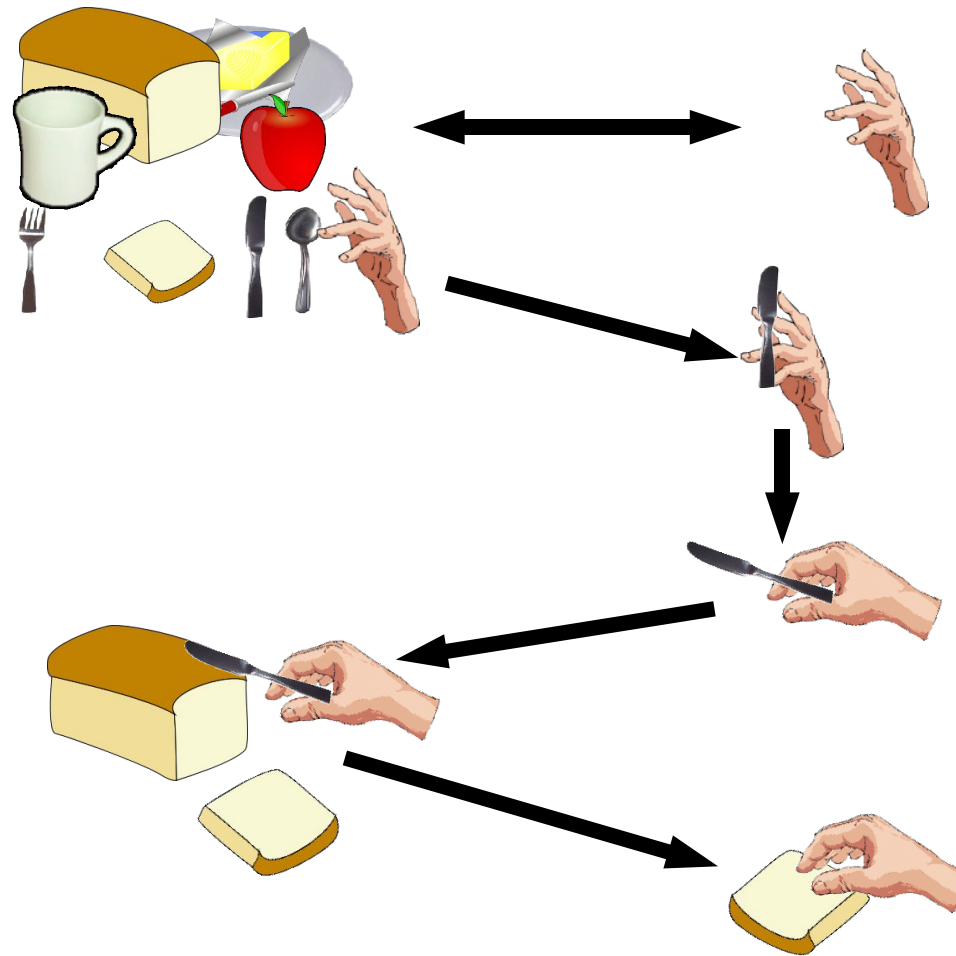
Learning Composite Relations

- How can we represent the direction “right”?



- Composition (set of changes)
- Abstraction (a symbol for the set)

Challenge: Eating a piece of bread



Anticipated Contributions

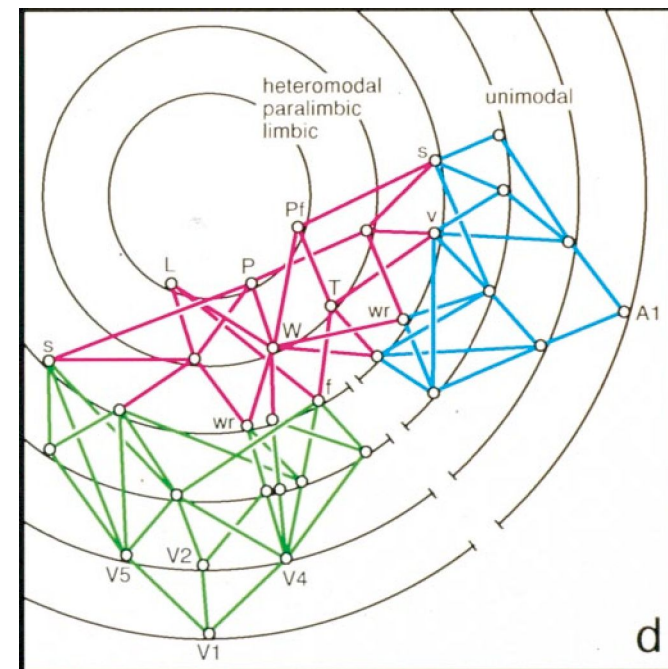
- Theory of self-wiring modules
- Learning about the world as a consequence of self-wiring
- Application to natural and engineered systems

Questions and Concerns

- How do I go from a few demonstrations to convincing evidence?
- How do I steer between the Scylla of toy systems and the Charybdis of signal processing?

Self-Configuring Brain Modules

- DNA too small (~1GB) for precise encodings
- Development depends on sensory input [Sur]
- Coordination develops late [Spelke]



Proposed partial network for the cerebral cortex [Mesulam]

Appendix: Milestones

Knowledge Encoded in Vocabulary

- Some naïve physics milestones

- Density

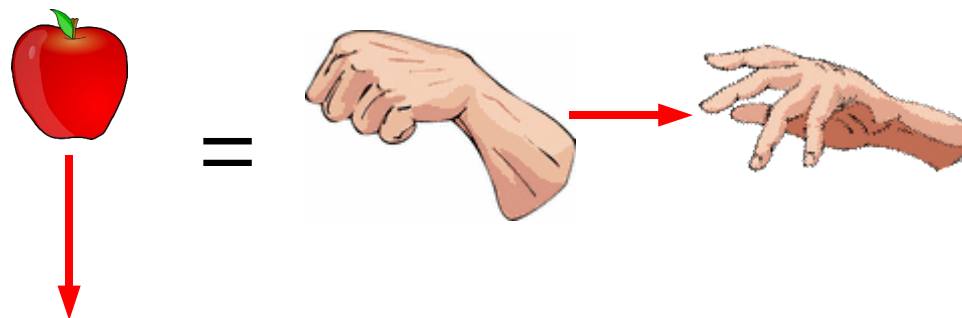
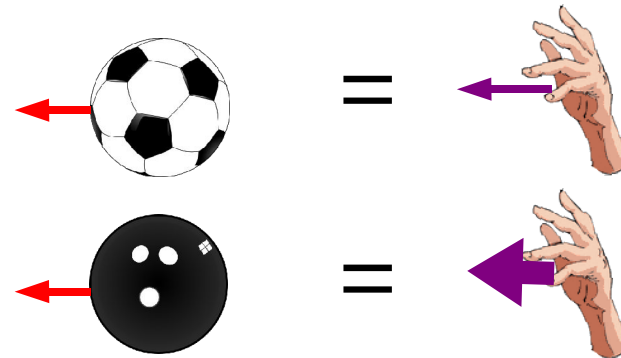
- Spelke principles

- Cohesion

- Continuity

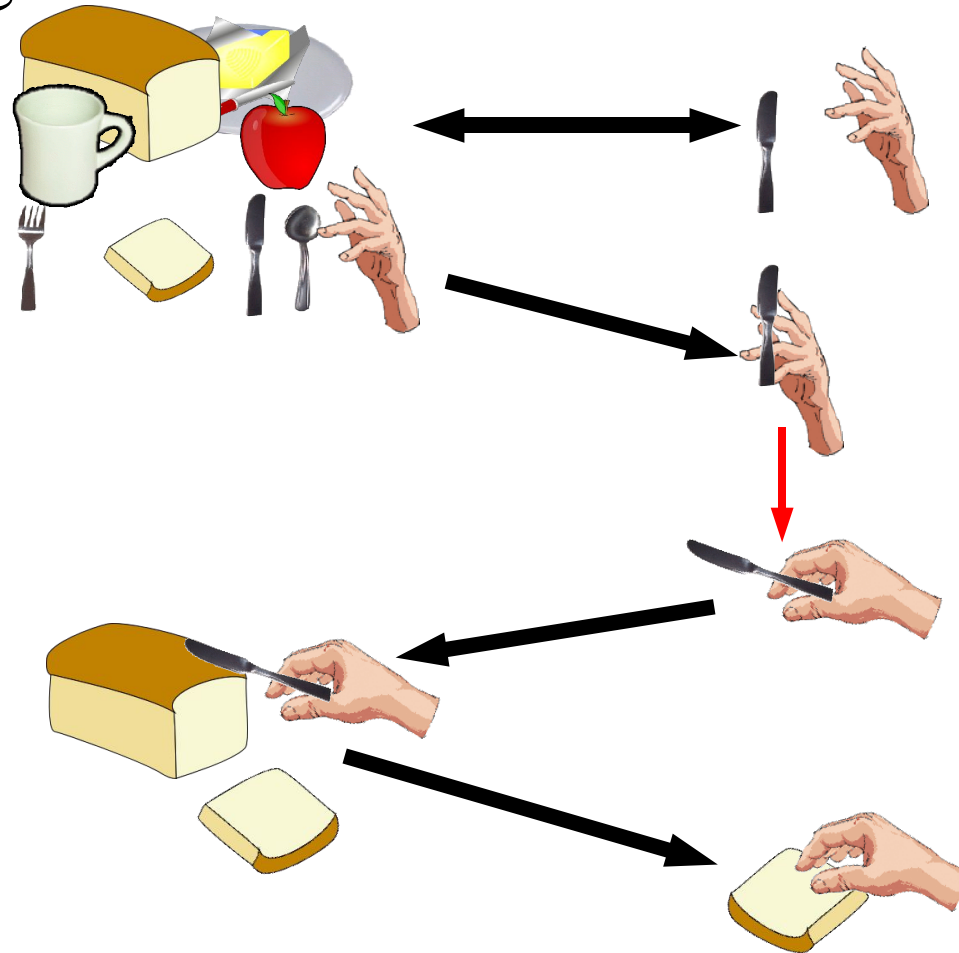
- Contact

- Gravity



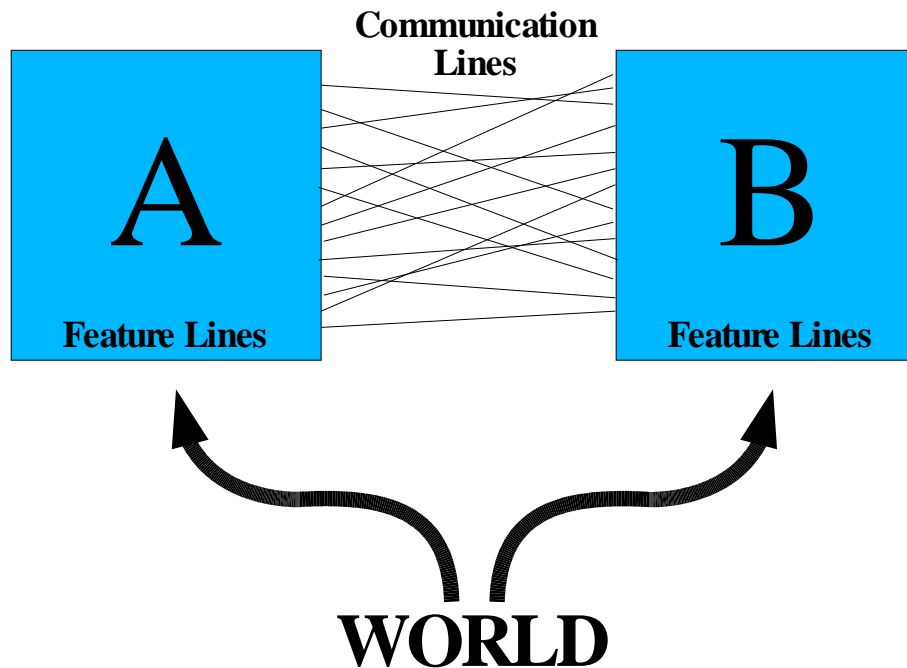
Using Encoded Knowledge

- Getting a slice of bread



Appendix: Communication Bootstrapping

Problem Definition

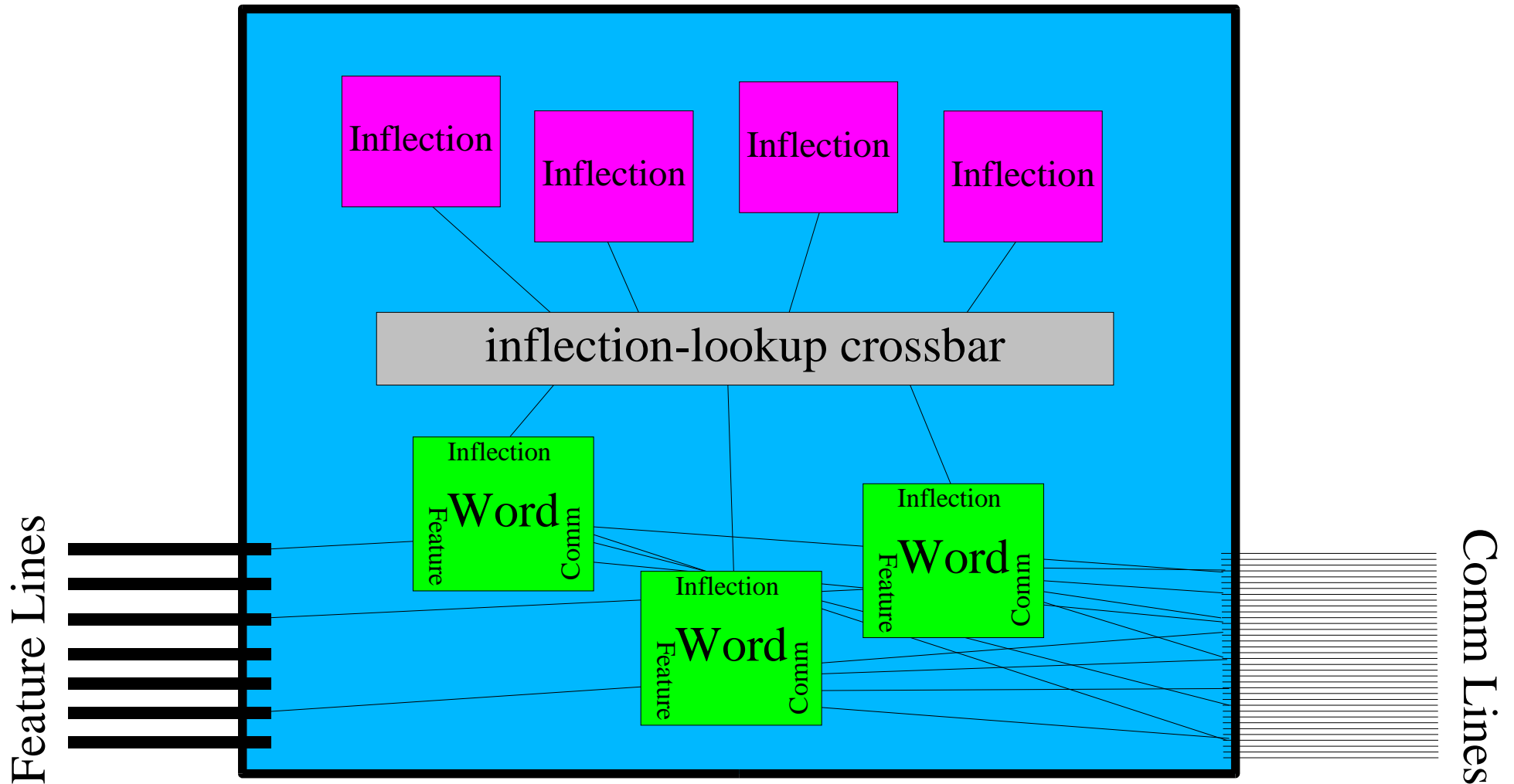


- World features: $\{(\text{symbol}, \text{role}), (\text{symbol}, \text{role})\dots\}$
- Comm line values: 0, +1, -1, X

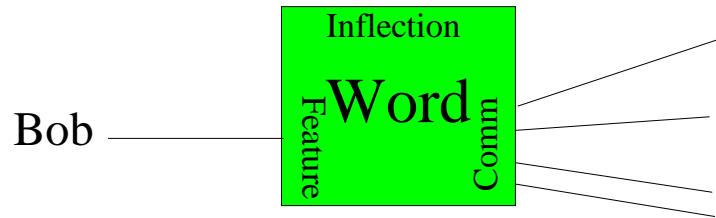
Comm. Bootstrapping Design Space

- Fragile, flaky components
- Parallel replicated structure is cheap; complex designs are expensive
- Serial computation is slow
- Bidirectional use of learned data
- No time-domain signals

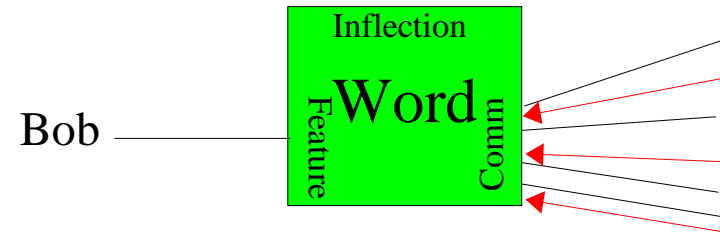
Bootstrapping Agent



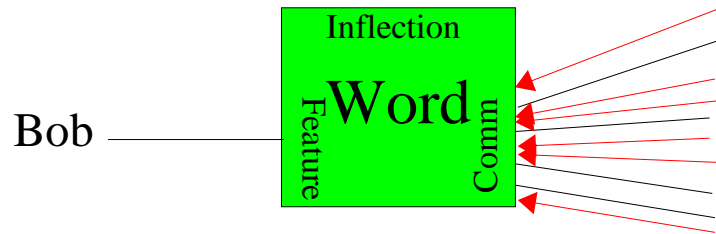
Learning a Word



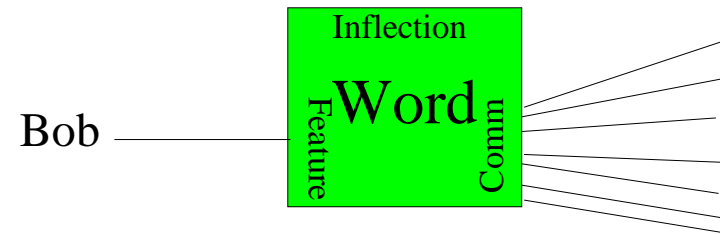
1. Choose random comm lines



3. Winnow possibles by intersection



2. Latch "possible" lines for partner



4. After several intersections start using remaining possibles

Learning Inflections

Inflection
Obj=0.8

Allocate and choose random value

Inflection
Obj=0.2

0.2

Set to value received from partner

Inflection
Obj=0.8

~~Inflection
Verb=0.82~~

On collision, resolve by deallocation

Channel Capacity

- Sparse concurrent usage → high capacity
 - 10K lines, 100 lines/word, 80% activation threshold, 6 concurrent words → 10^{12} word capacity