A Neurophysiological Model of Grammatical Construction Processing with Cross-Linguistic Validation and Robotic Implementation

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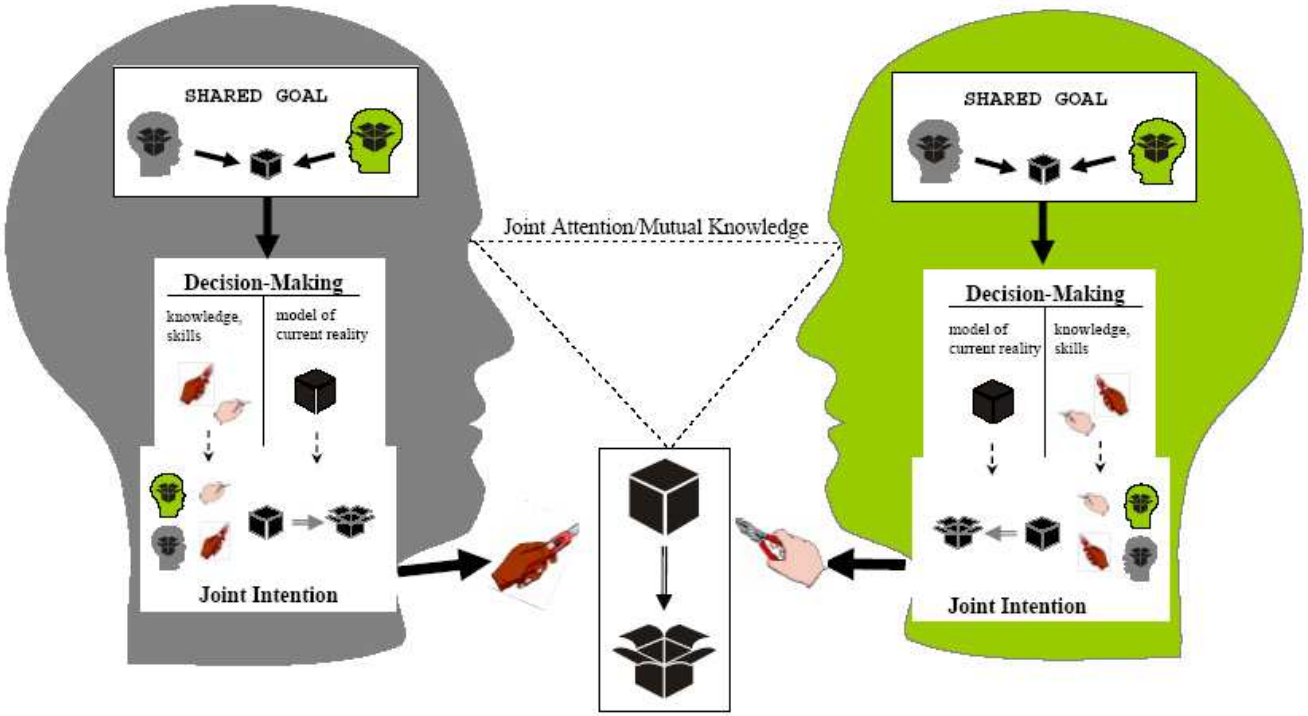
A Cognitive Systems Approach to Language

- Requirements on language: what is it for?
- What strategies can be employed?
- How can this be realized in neurophysiology?
- A Model of Grammatical Construction Processing
- How can the model access « meaning »?
- Language in the context of Cooperation
- Perspectives

What is language for?
Sharing Mental States



Tomasello M, Carpenter M, Call J, Behne T, Moll HY (2005) **Understanding and sharing intentions: The origins of cultural cognition**, Beh. Brain Sc;. 28; 675-735.

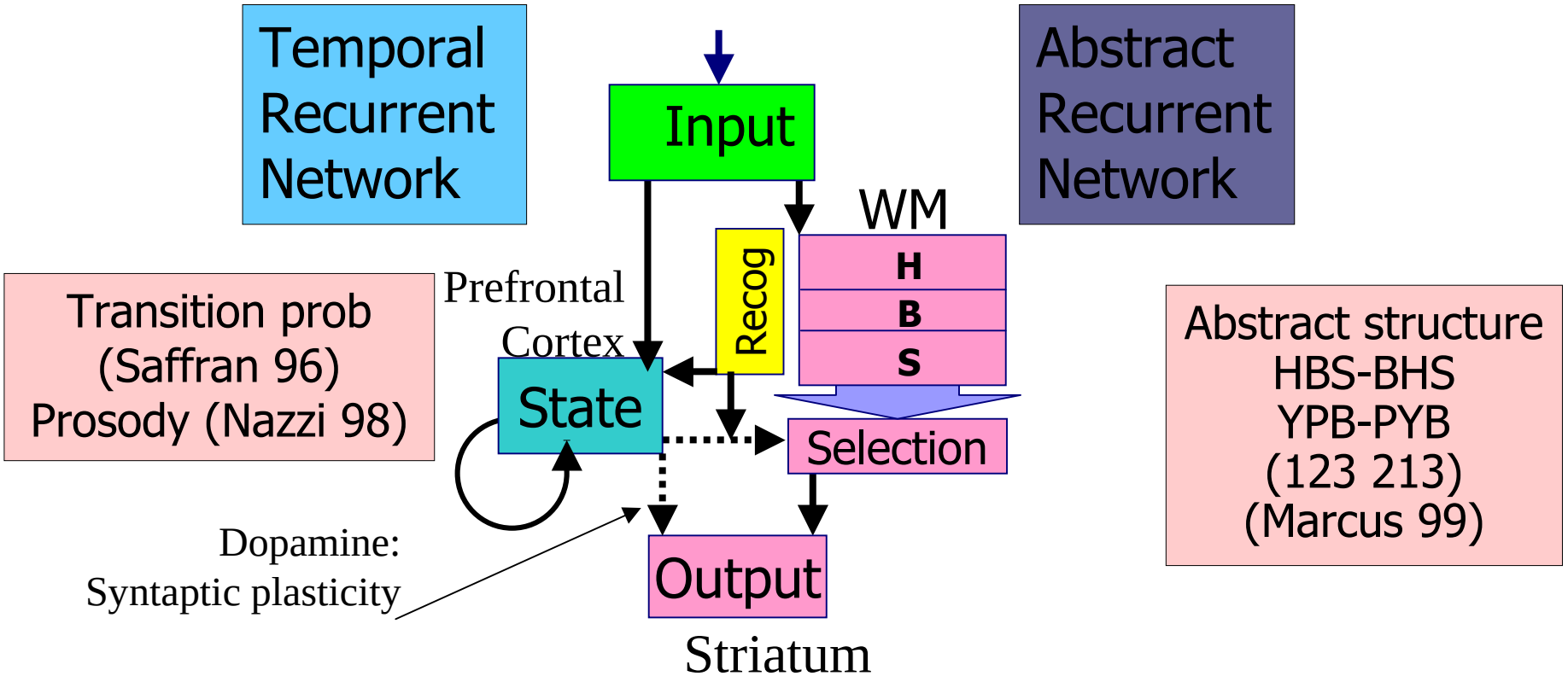
Requires a linearization of complex multidimensional representations

What encoding strategies can be employed?

- In the morphosyntactic arena, there is an item-based competition between *word orders* and *grammatical markings* centered on valence relations.
- At the core of syntactic processing is the learning and use of *item-based constructions*
  - children first learn that a verb like *throw* takes three arguments (thrower, object thrown, recipient)
  - by comparing groups of these item-based patterns through analogy, *children can then extract broader class-based patterns*

Competition Model - MacWhinney 2004, Bates & MacWhinney 1987
Usage Based Learning – Tomasello 2003
Construction Grammar – Goldberg 1999

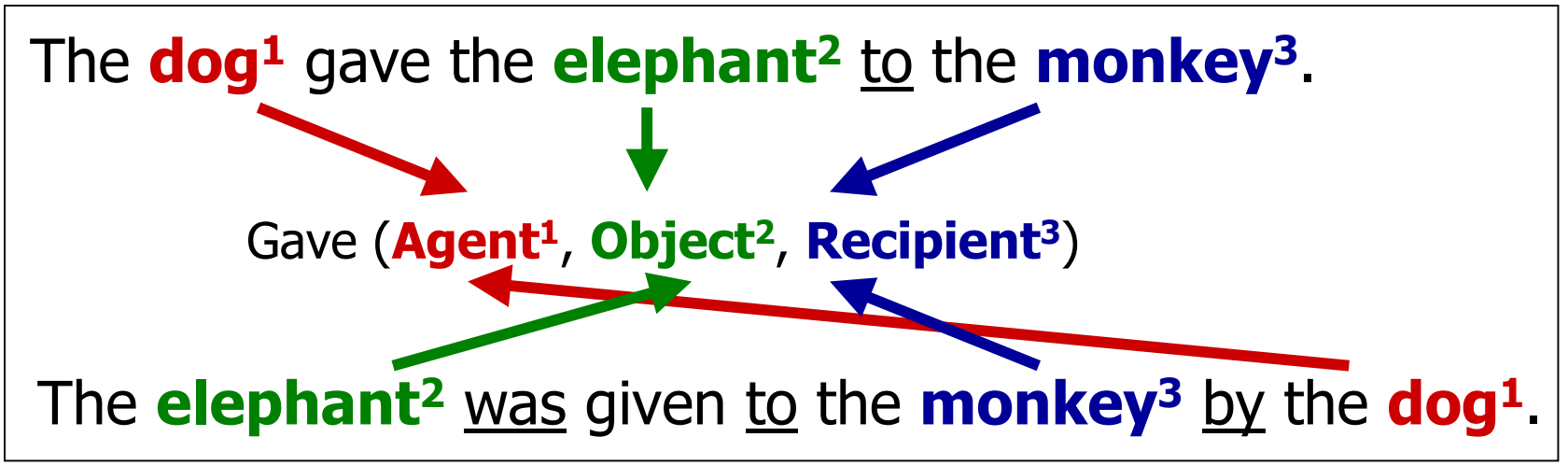
Neurophysiology of Serial, Temporal and Abstract Sequences



Dominey, P. F., & Ramus, F. (2000). Neural network processing of natural language: I. Sensitivity to serial, temporal and abstract structure of language in the infant. *Language and Cognitive Processes, 15*(1), 87–127.

(Dominey et al. J Cognitive Neuroscience 1995, 1998)

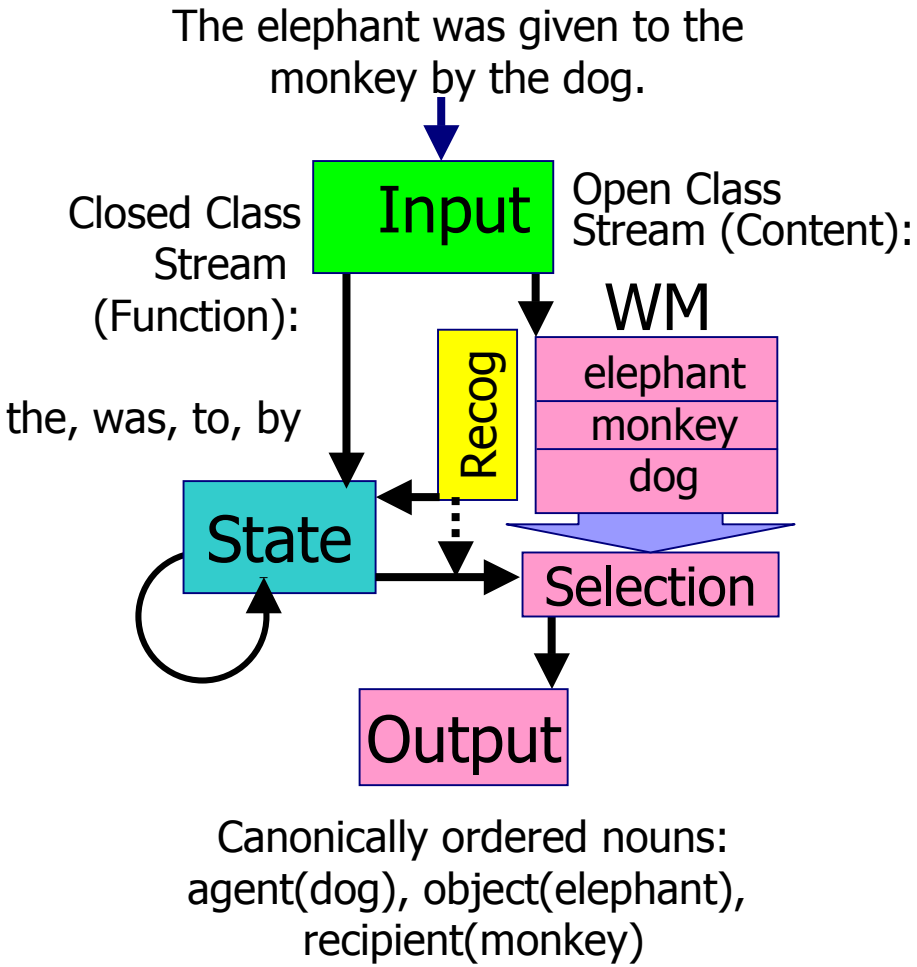
Extension of Abstract Structure to Grammatical Constructions



- Different surface forms map to same meaning
- Indicated by function words (was, to, by)

- Non-Linguistic correlate – "equivalence hypothesis"
  - 123X123, 231Y123

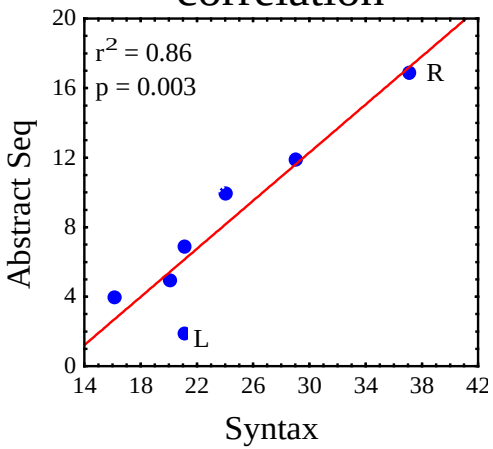
Abstract sequencing model learns grammatical constructions



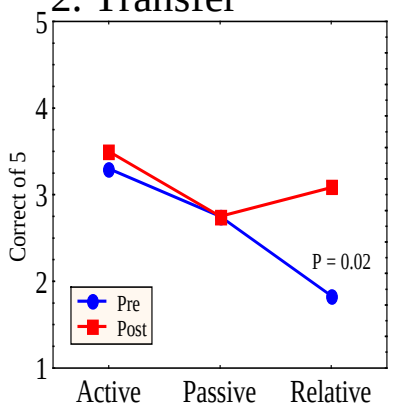
Dominey et al (2003) Brain and Language

Validating the ‘Equivalence Hypothesis’

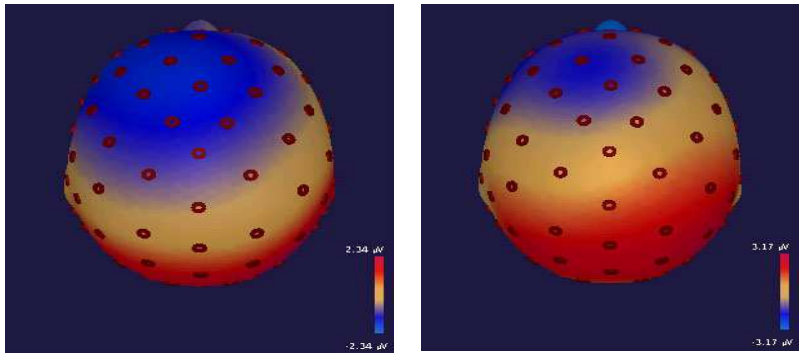
1.Agrammatic correlation



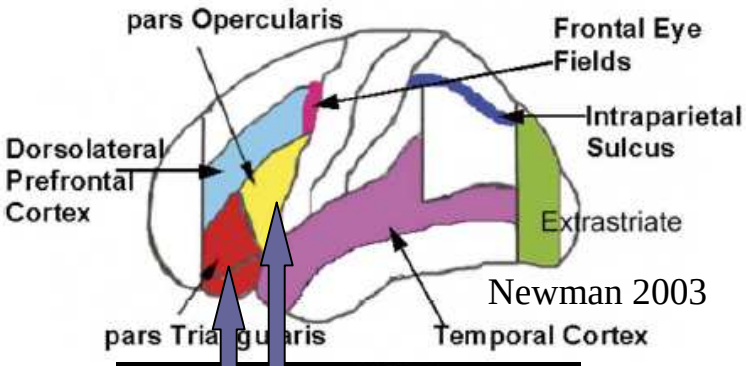
2. Transfer



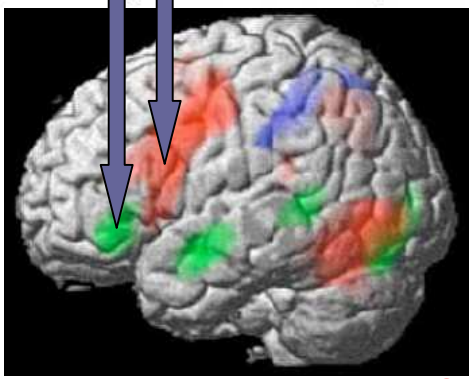
3. ERP



Language Sequences



Newman 2003



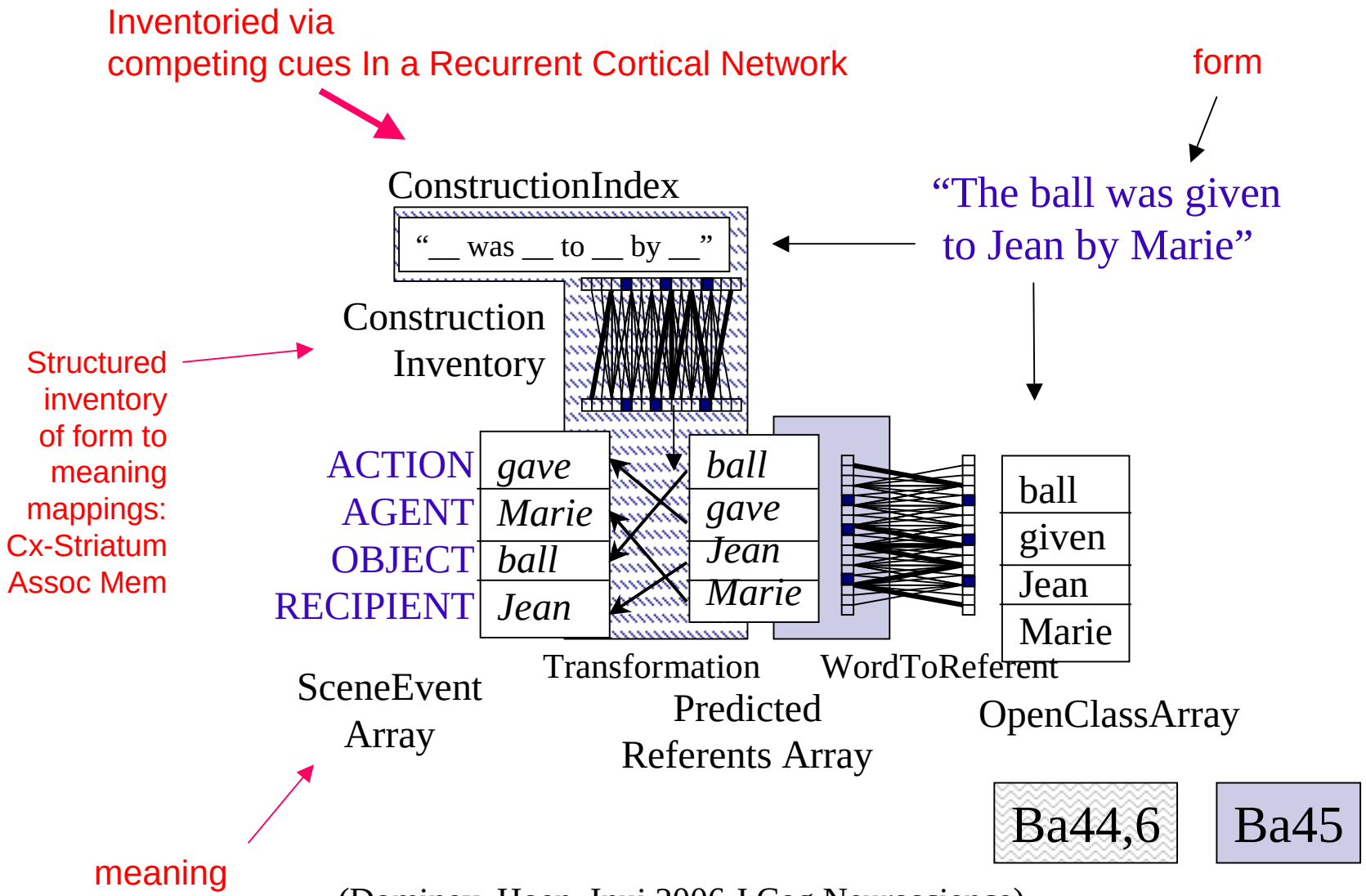
4. fMRI

Language **Language & Seq**

4. Hoen, Dominey et al Cortex 2006

1. Dominey et al B&L 2003, 2. Hoen, Dominey et al. NeuroReport 2003, 3. Hoen & Dominey NeuroReport 2003

A Neurolinguistic Model of Grammatical Construction Processing



(Dominey, Hoen, Inui 2006 J Cog Neuroscience)

Cross-Linguistic Validation: Japanese

Block-ga circle-wo oshita triangle-ni-yotte tatakareta.
Circle-wo oshita triangle-ni-yotte block-ga tatakareta.
The block was hit by the triangle that pushed the circle.
Pushed(triangle, circle), Hit(triangle, block)

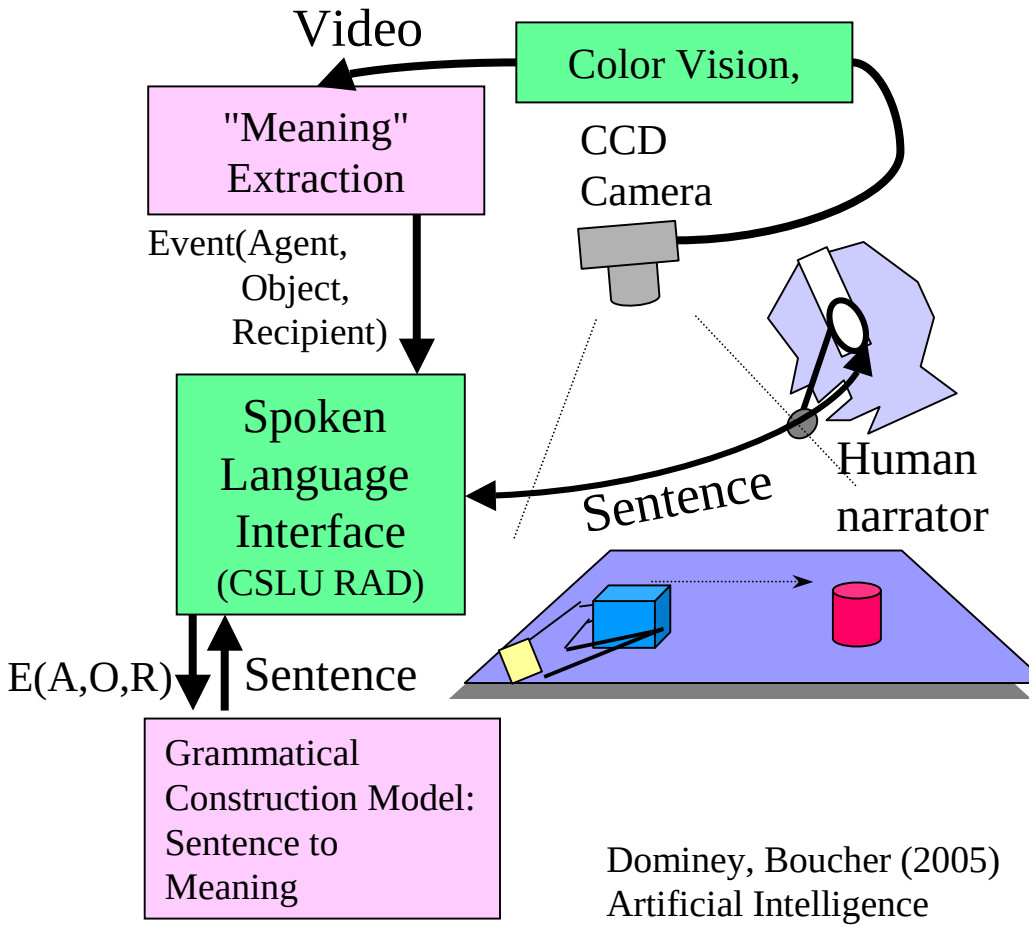
Circle-wo tataita block-ga triangle-ni-yotte osareta.
Triangle-ni-yotte circle-wo tataita block-ga osareta.
The block that hit the circle was pushed by the triangle.
Hit(block, circle), Pushed(triangle, block)

Block-ga circle-wo oshita triangle-wo tataita.
Circle-wo oshita triangle-wo block-ga tataita.
The block hit the triangle that pushed the circle.
Pushed(triangle, circle), Hit(block, triangle)

N = 26 constructions
Dominey & Inui CoLing 2004
Dominey, Hoen, Inui JoCN 2006

Towards Grounded Meaning: Linking Language to Action

- "Perceptual Processing"
  - Color based segmentation
  - Speech recognition, syntheses, dialog mgmt (CSLU RAD)
- "Cognitive Processing"
  - Extraction of "Meaning" : Action Perception
    - Events from spatiotemporal schemas
  - Sentence-Meaning mapping
    - Grammatical Constructions

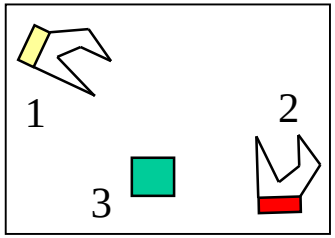


Dominey, Boucher (2005) Artificial Intelligence

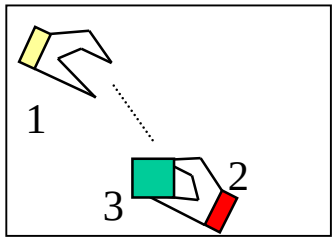
Action Perception: Extracting meaning from vision

- Events categorized in terms of perceputal primitive “contact”
  - *contact(agent, objet, duration)*
  - *Position,velocity*
- Single-contact events
  - *touch, push, take* can be described as contacts, and durations.
  - duration: *Touch < Push < Take*
  - Agency =f(relative velocity)
- Mutliple-contact events
  - Give(agent, object, recipient)
  - Take(agent, object, recipient)

Give(2, 3, 1)

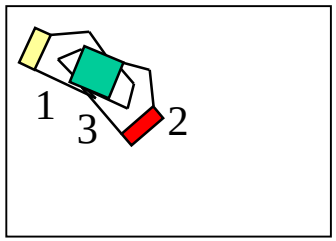


Contact (2, 3)



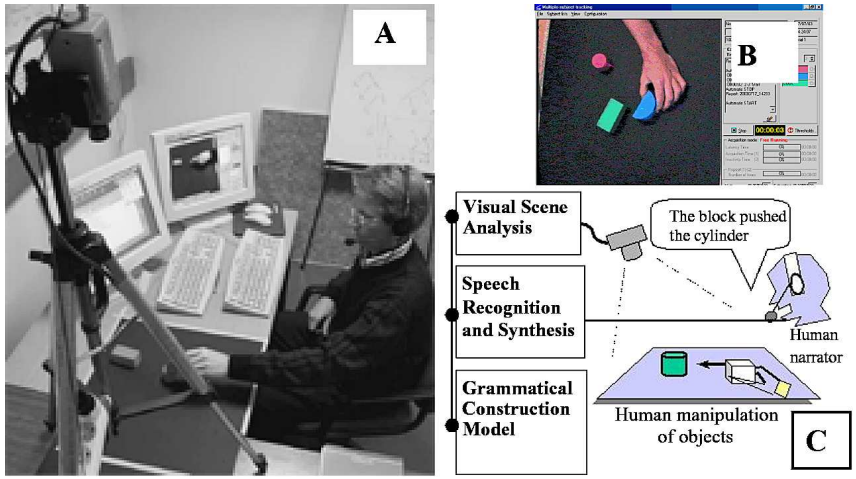
Contact (3, 1)

Contact (2, 1)



Learning grammatical constructions from naive human subjects in an "unconstrained" situation

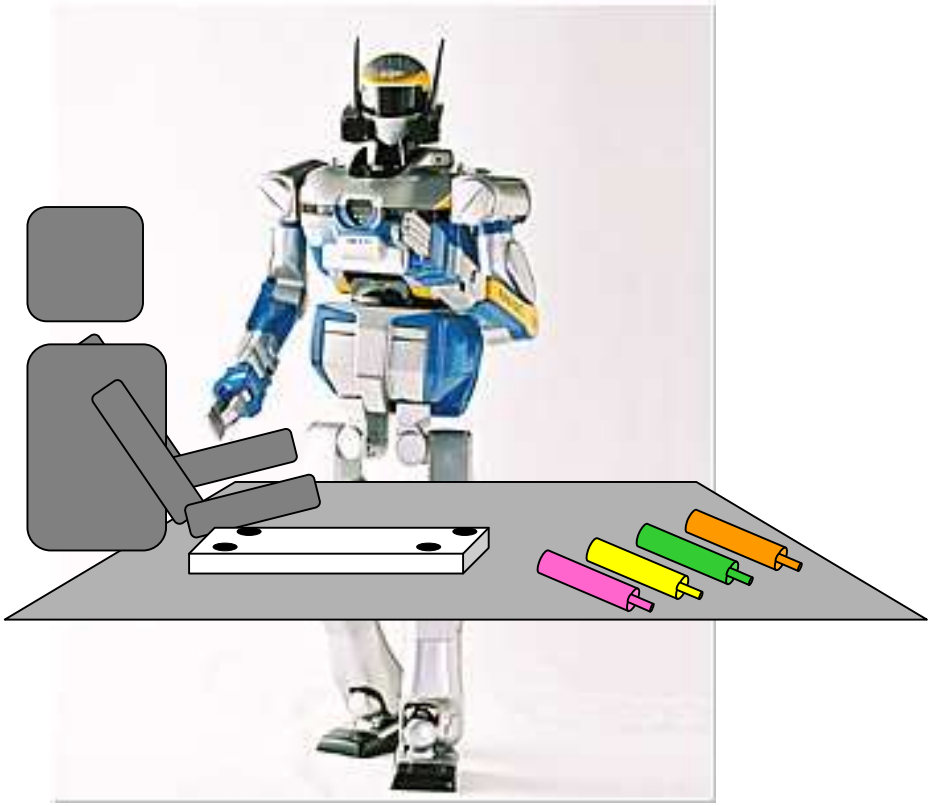
- 4 Subjects Generate <Sentence, Meaning> pairs by narrating video events
  - 282 Sentence, meaning pairs:
- Train the model on ½ <Sentence, Meaning> pairs
- Test generalization on second ½
- 85% Accuracy on Training and Test sets



Dominey, Boucher (2005) Artificial Intelligence

Language in the Context of Cooperation

Cooperative Table Assembly Scenario



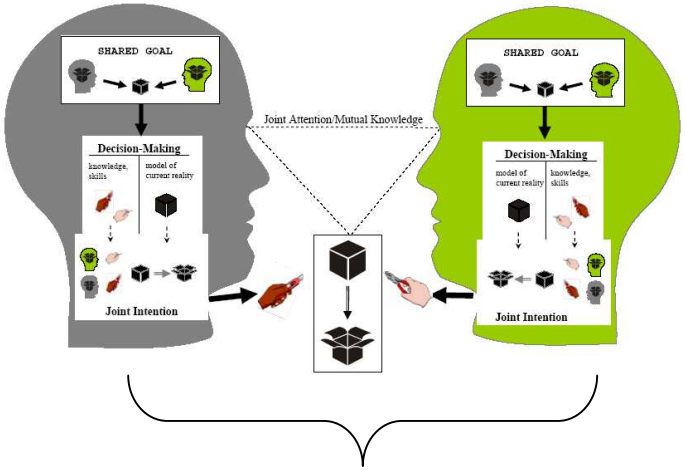
- Robot Helps Users to Assemble a Table
- Functional Requirements
  - The robot should be able to:
  - Respond to human spoken commands with simple behaviors
    - Open left hand, turn right,..
    - Grasp(X): X in <visible>
  - Learn complex behaviors constructed from the primitives
    - Give me the orange leg
    - Hold the table

Teach Actions with Grammatical Constructions

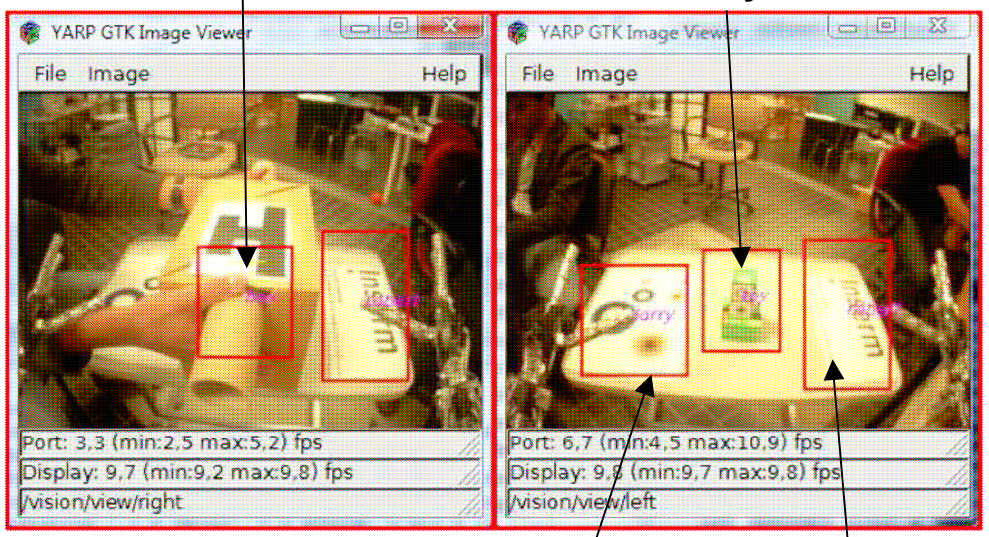
- Give me the ***green*** leg
  - Take the ***green*** leg
  - Turn right
  - Open right hand
- Training with one example
  - *Green* is passed as an argument to TAKE
  - Learned procedure generalizes over (yellow, rose, green, orange)
  - Powerful learning capability with procedures that take variables
- Embodiment of lexical categories
  - Verbs – procedures
  - Nouns – arguments

Part of Joint Robotics Laboratory project, CNRS LAAS Toulouse,
Dominey, Mallet, Yoshida (2009) Intl. J Humanoid Robotics

Cooperative Plans from Observation

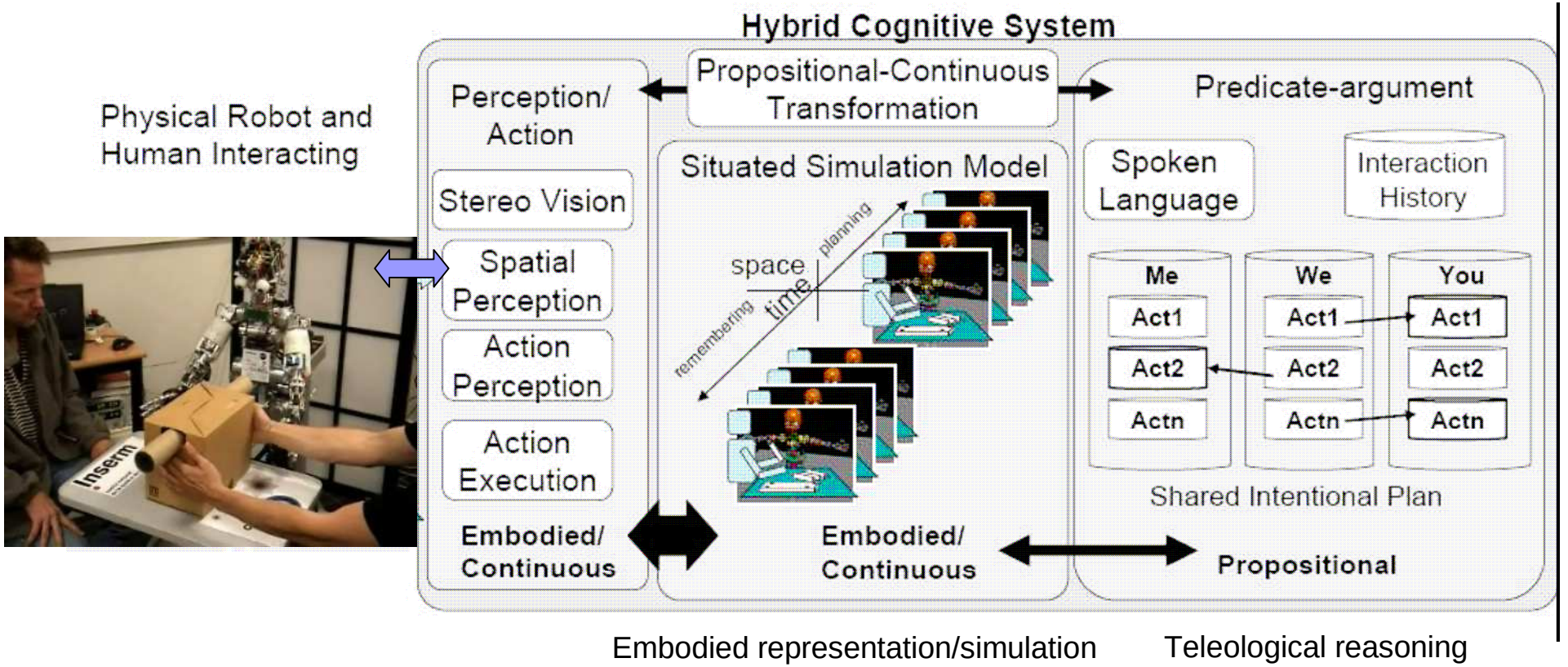


- Perceive action
- Attribute agency
- Form shared plan
- Use it in cooperation
- Modify the plan with discourse
  - “after, because, if-then …”



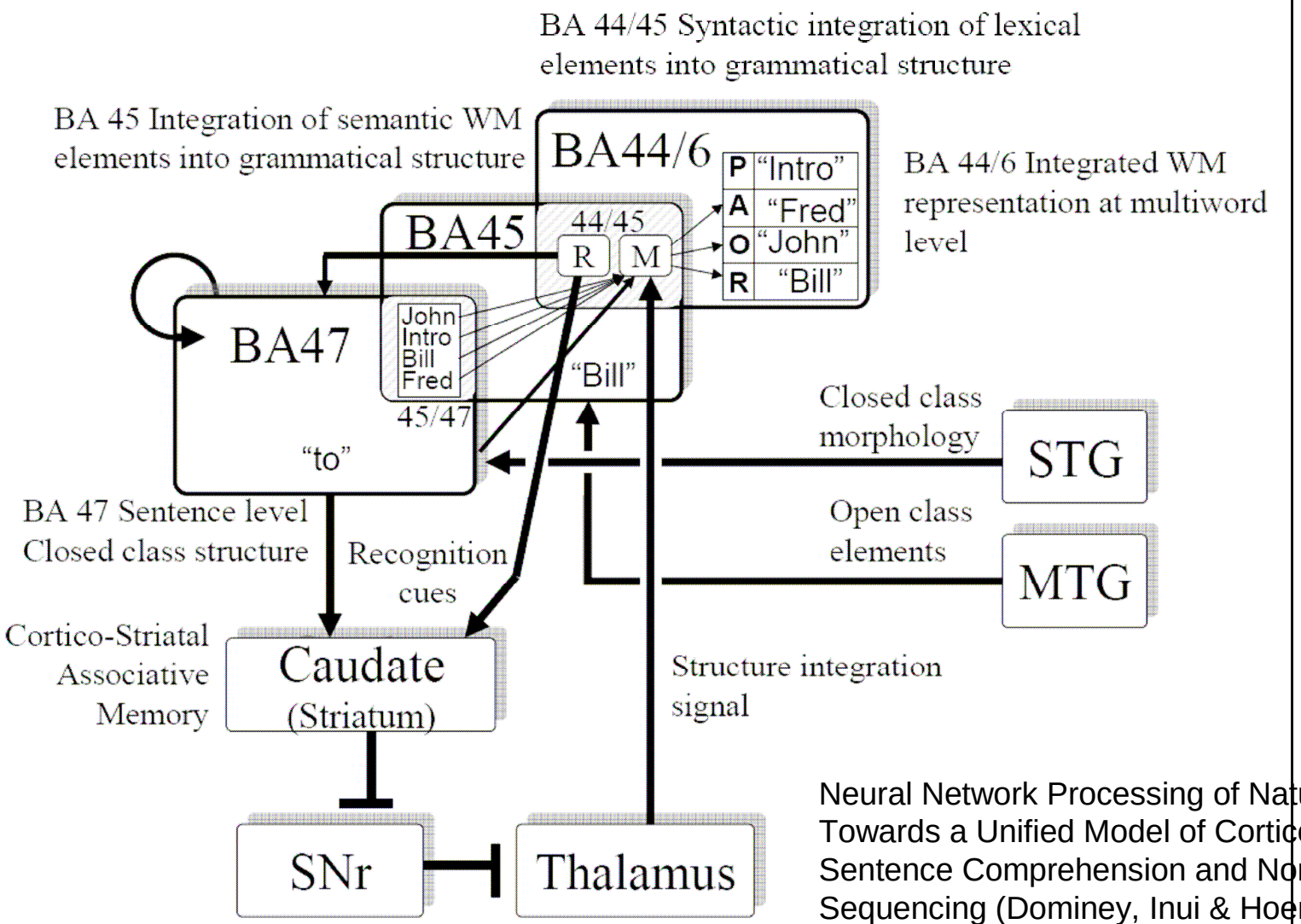
Lallee, Warneken, Dominey (2009)

Perspectives (1) Hybrid Telelogical/Embodied Cognitive System



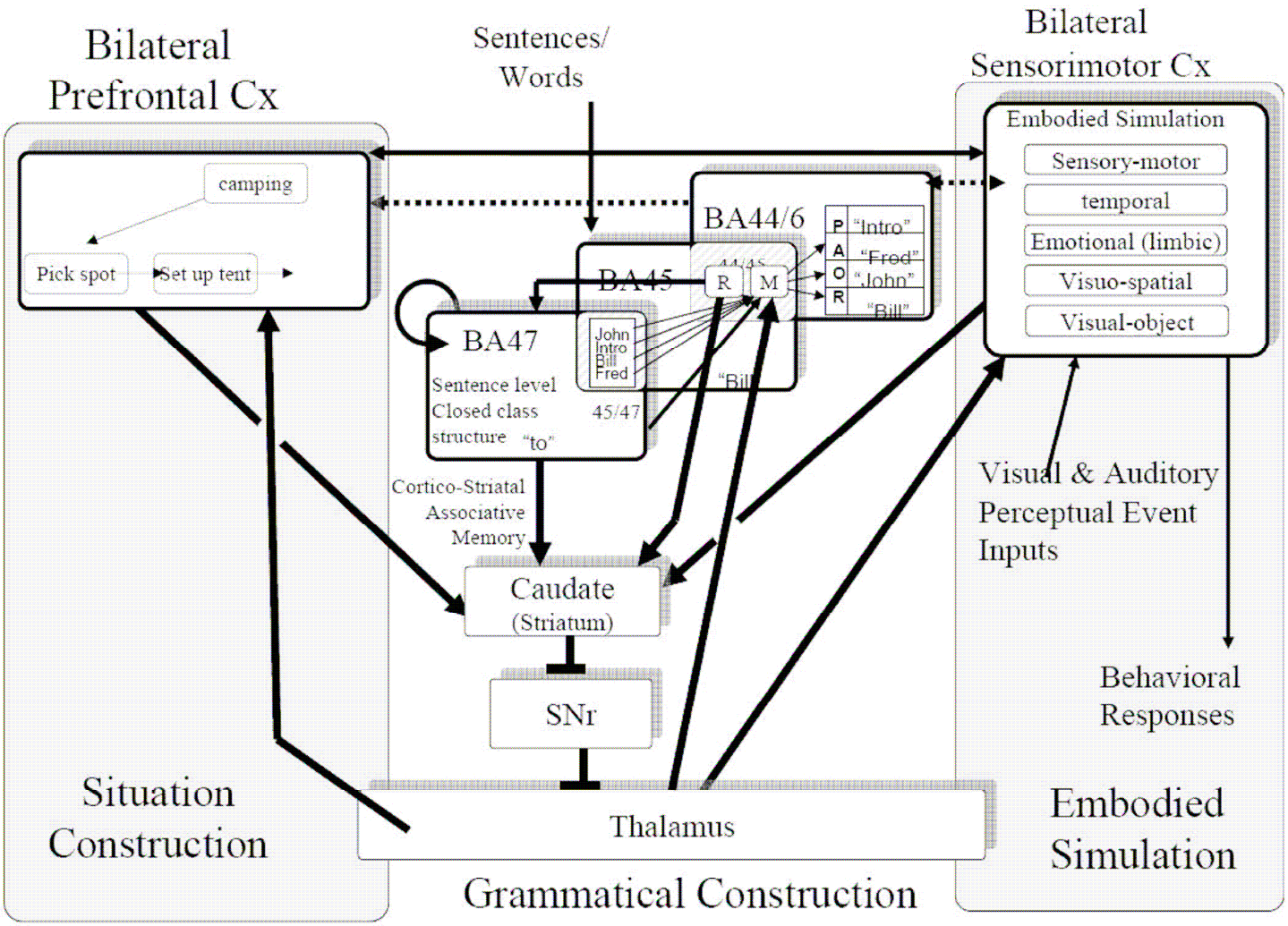
Madden, Hoen, Dominey (2009) Brain and Language
iCub project – Lyon, June 2009

Perspectives (2) Detailed Neurophysiology of On-line sentence processing



Neural Network Processing of Natural Language: II. Towards a Unified Model of Corticostriatal Function in Sentence Comprehension and Non-Linguistic Sequencing (Dominey, Inui & Hoen 2009)

Hybrid Comprehension Model



Madden, Hoen, Dominey (2009) Brain and Language

Conclusion & Perspectives

- Requirements on language: what is it for? – Cooperation
  - Linearlization of a high dimensional representation
- What strategies can be employed
  - Word order, grammatical markers, prosody, … Cue Competition
  - Grammatical constructions – form to meaning mapping
- How can this be realized in neurophysiology
  - Specialized working memories in BA47,45,44,6 and the corticostriatal system
  - Link to the embodied representation of meaning
- Perspectives
  - How Is Meaning Generated? From interaction: Enrich the interaction and representation – States, Goals, Causality
  - How does the sensory-motor system participate in learning and comprehension - Embodied language comprehension
  - What is the Underlying Neurophysiology for language learning – linking language to meaning
  - Artificial Systems (robots, neural networks) will play a central role in the study of language acquisition.

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