AI : The Standpoint of Developmental Robotics

Philosophy & Theory of AI - 2013

Jean-Christophe Baillie
Aldebaran's AI Lab

ALDEBARAN Robotics


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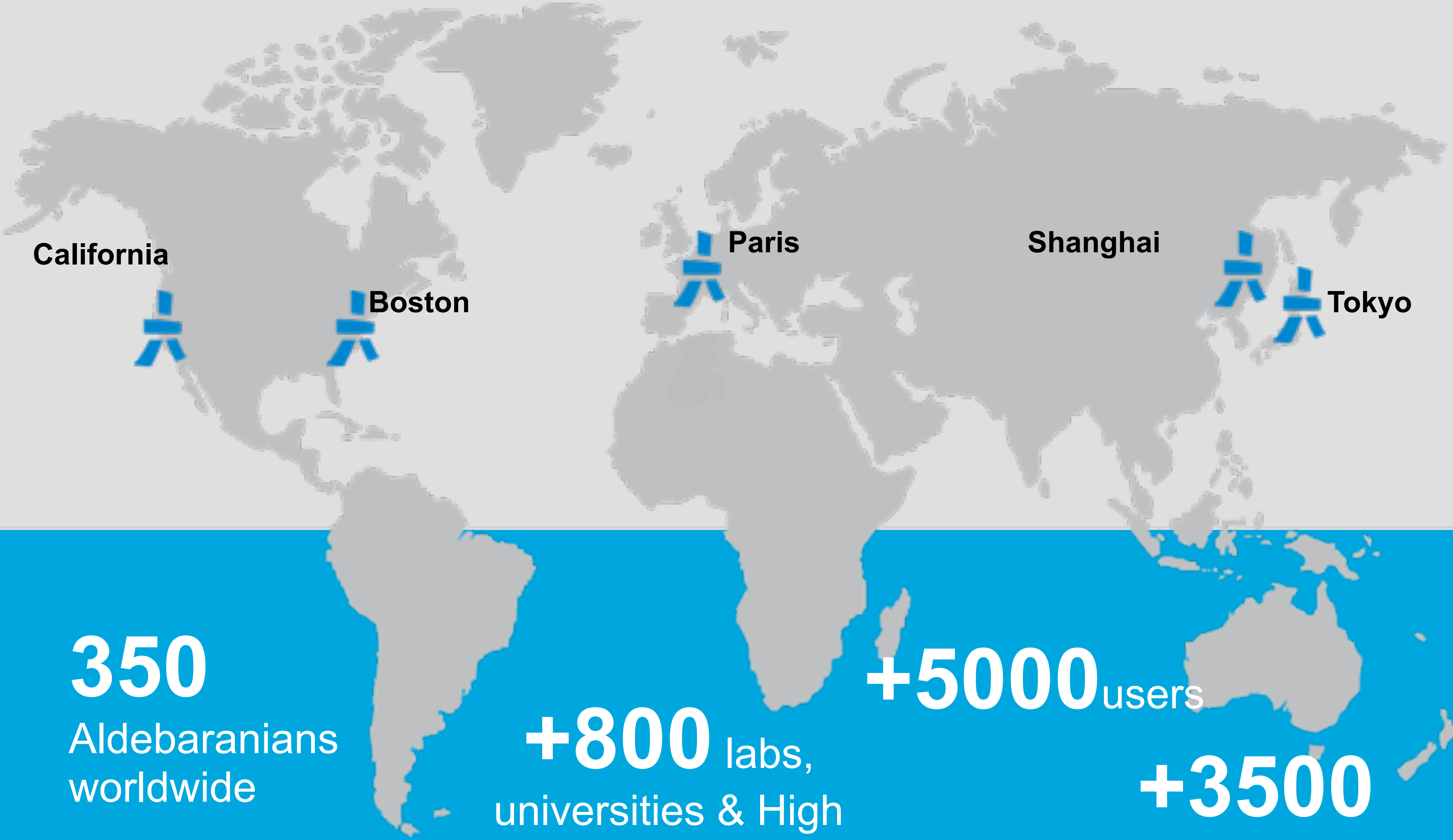
About Aldebaran Robotics



350
Aldebaranians worldwide

+800 labs, universities & High Schools as customers

+5000 users

+3500
NAOs in use

Research Groups: the A-Lab

Applied Research

- MECHATRO Lab
- DYNAMICS Lab
- INTERACTION Lab
- SYSTEM Lab

Fundamental Research

- AI Lab Paris

AI Lab: Where do we stand?

Three approaches to AI research:

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- **Applied AI**: solve engineering problems using learning methods, heuristics, etc.

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AI Lab: Where do we stand?

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AI Lab: Where do we stand?

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AI Lab

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Developmental Robotics

Not the end result ... but the process

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Developmental Robotics

inspiration (among others) from developmental psychology

Not the end result

... but the process

Grounding Symbols

The Symbol Grounding Problem

Stevan Harnad, 1990:

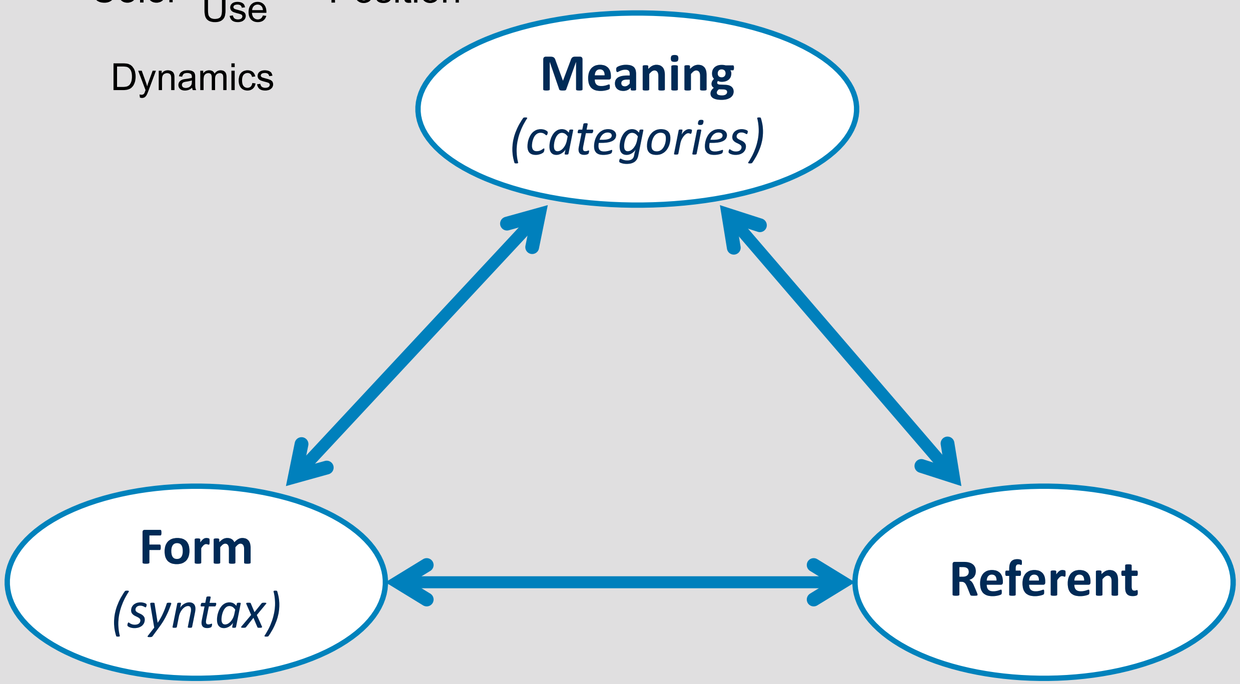
"How can the semantic interpretation of a formal symbol system be made ***intrinsic*** *to the system, rather than just parasitic on the meanings in our heads?"*

Semiotic Triangle

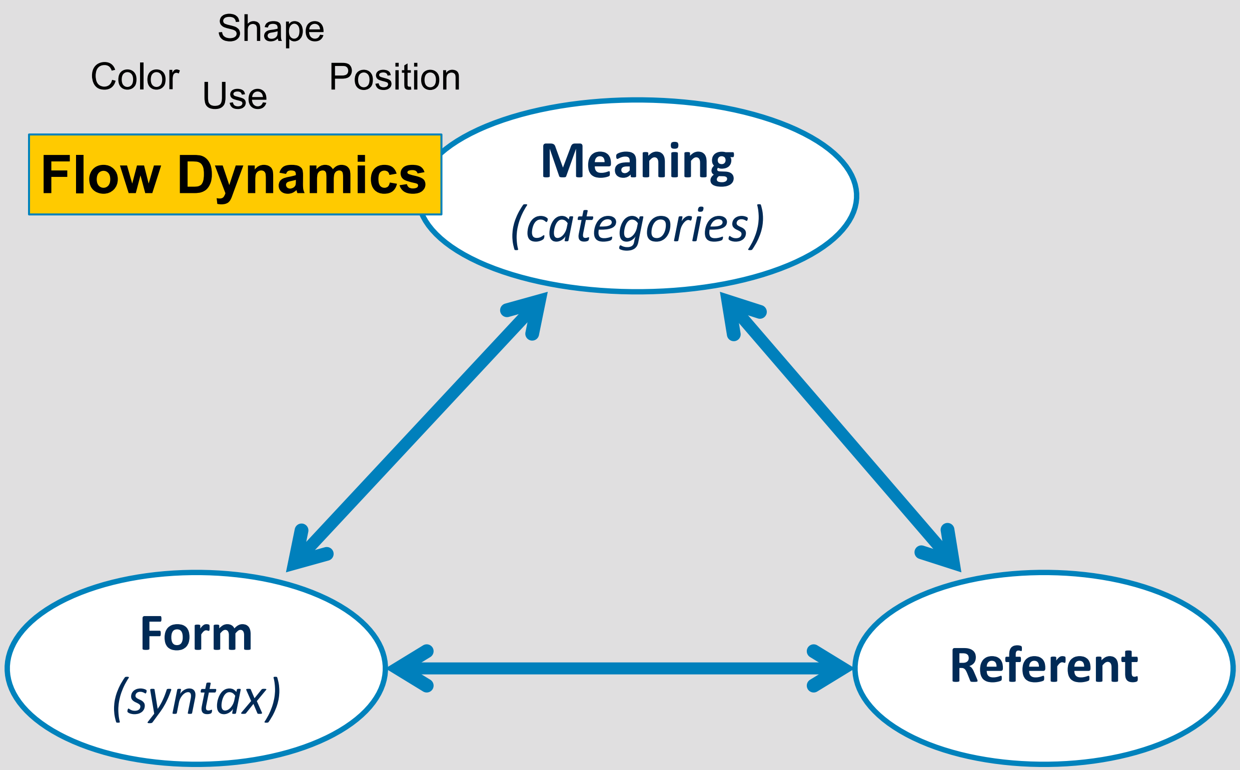
Shape

Color Use Position

Dynamics



Semiotic Triangle



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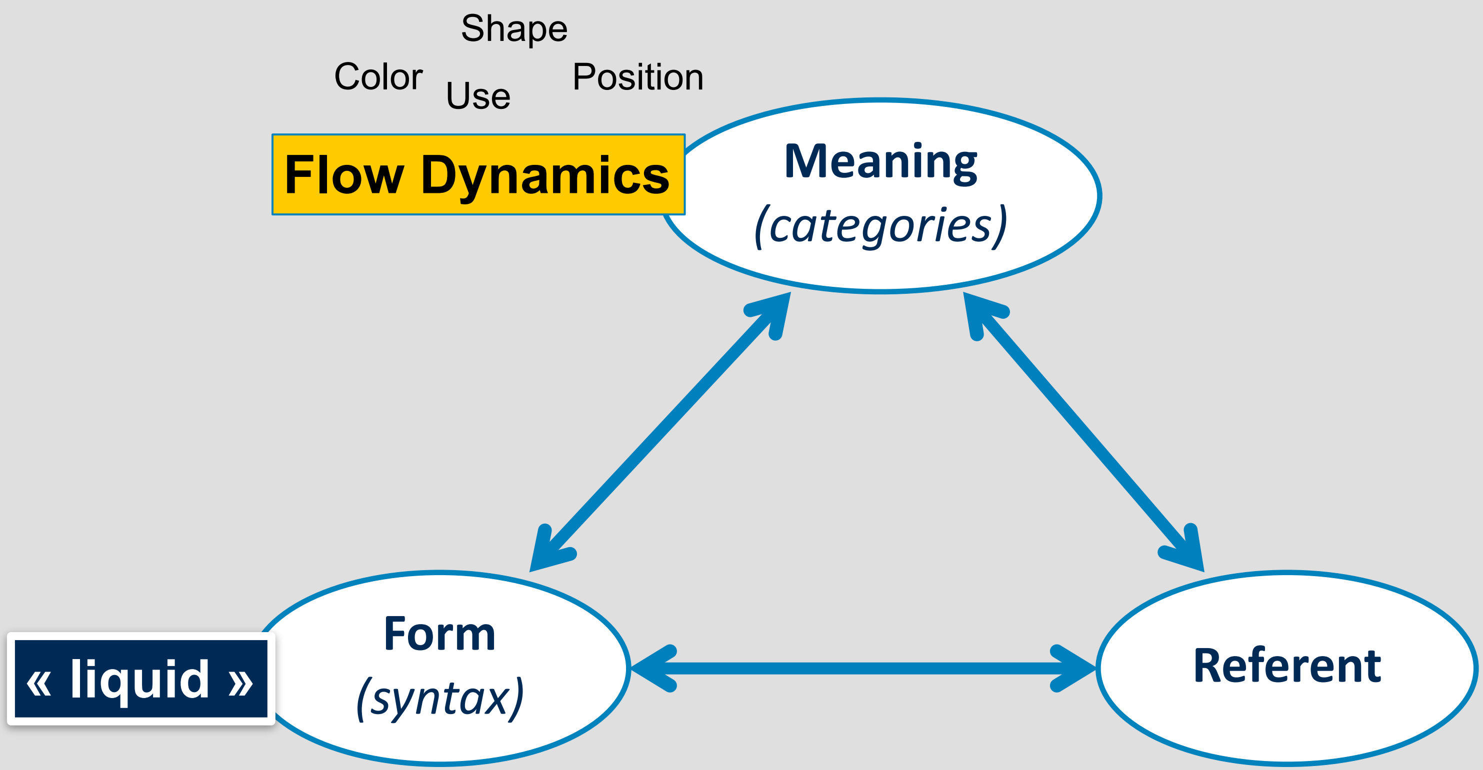

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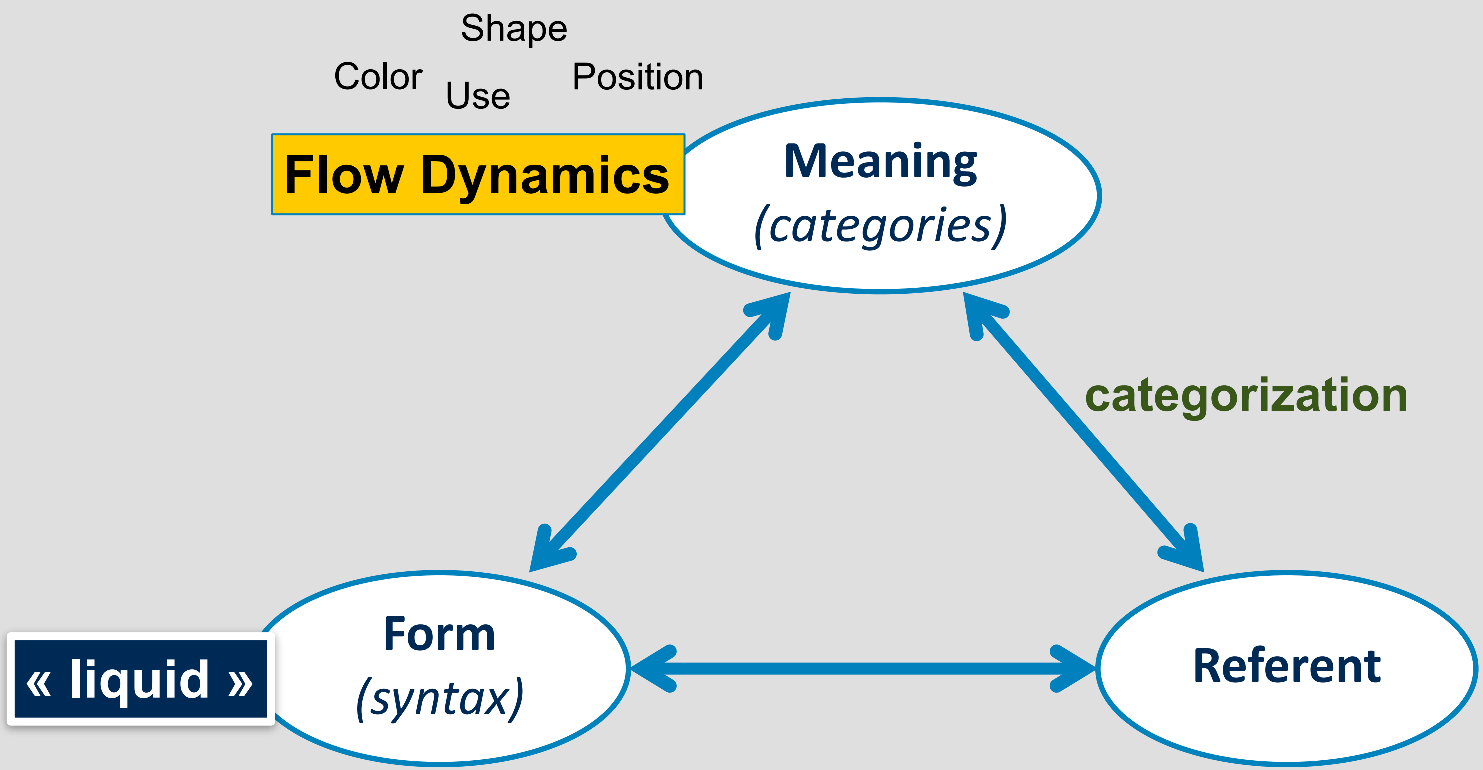

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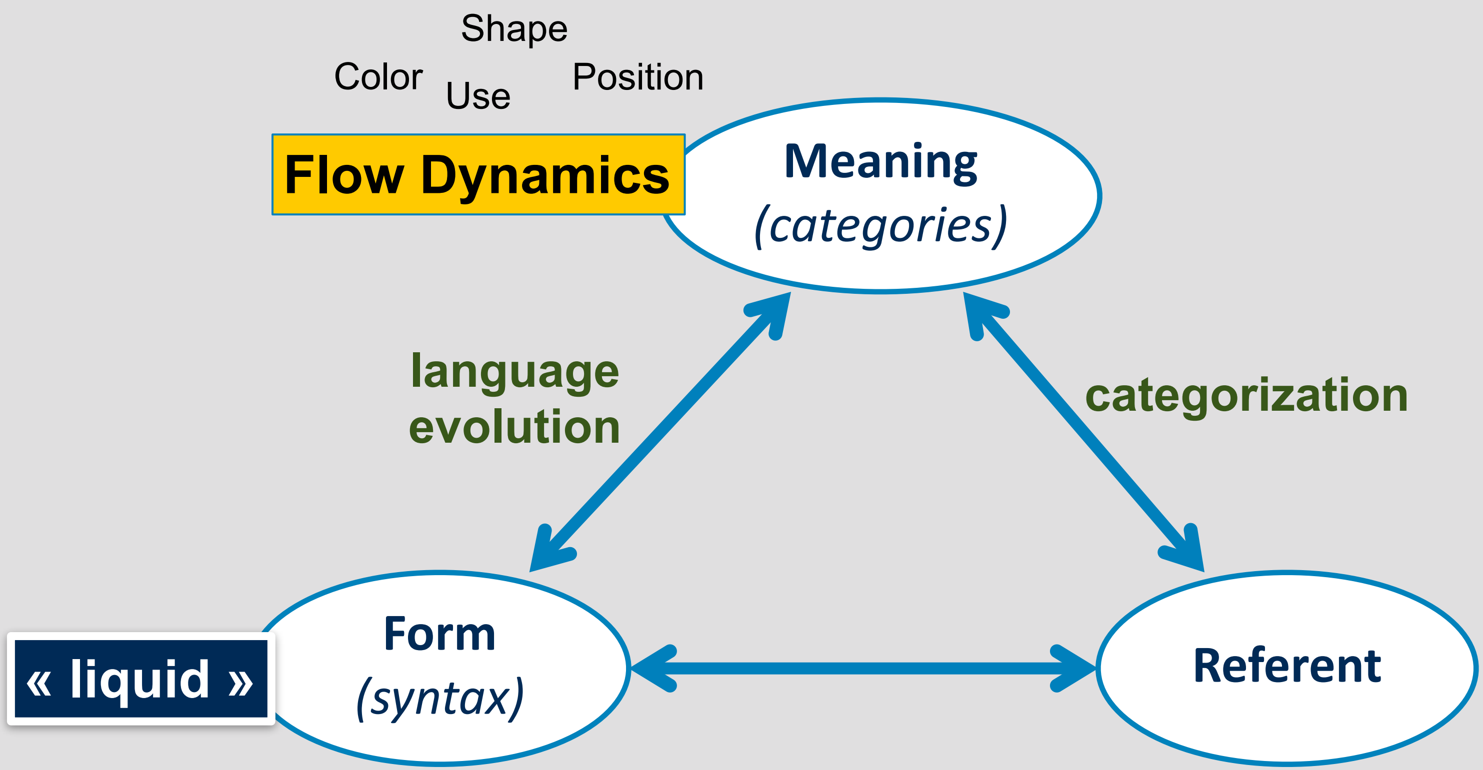

Why is grounding important for AI?

- because grounded cognition is important for robots and embedded systems? (*and they interact with us*)

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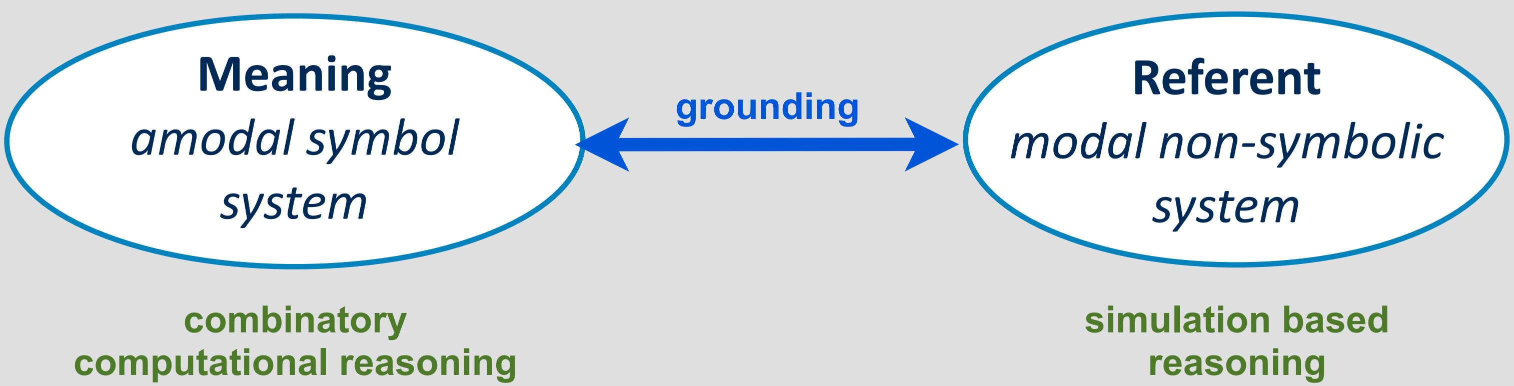
- because grounded cognition is important for robots and embedded systems? (*and they interact with us*)
- because grounded cognition provides access to **grounded forms of reasoning** (Barsalou 2008)



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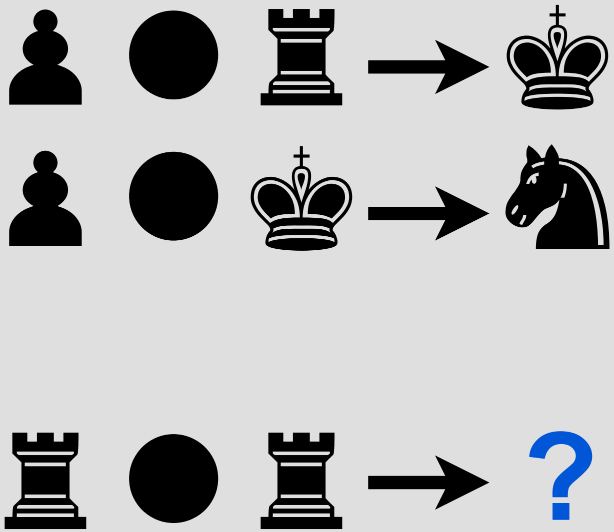
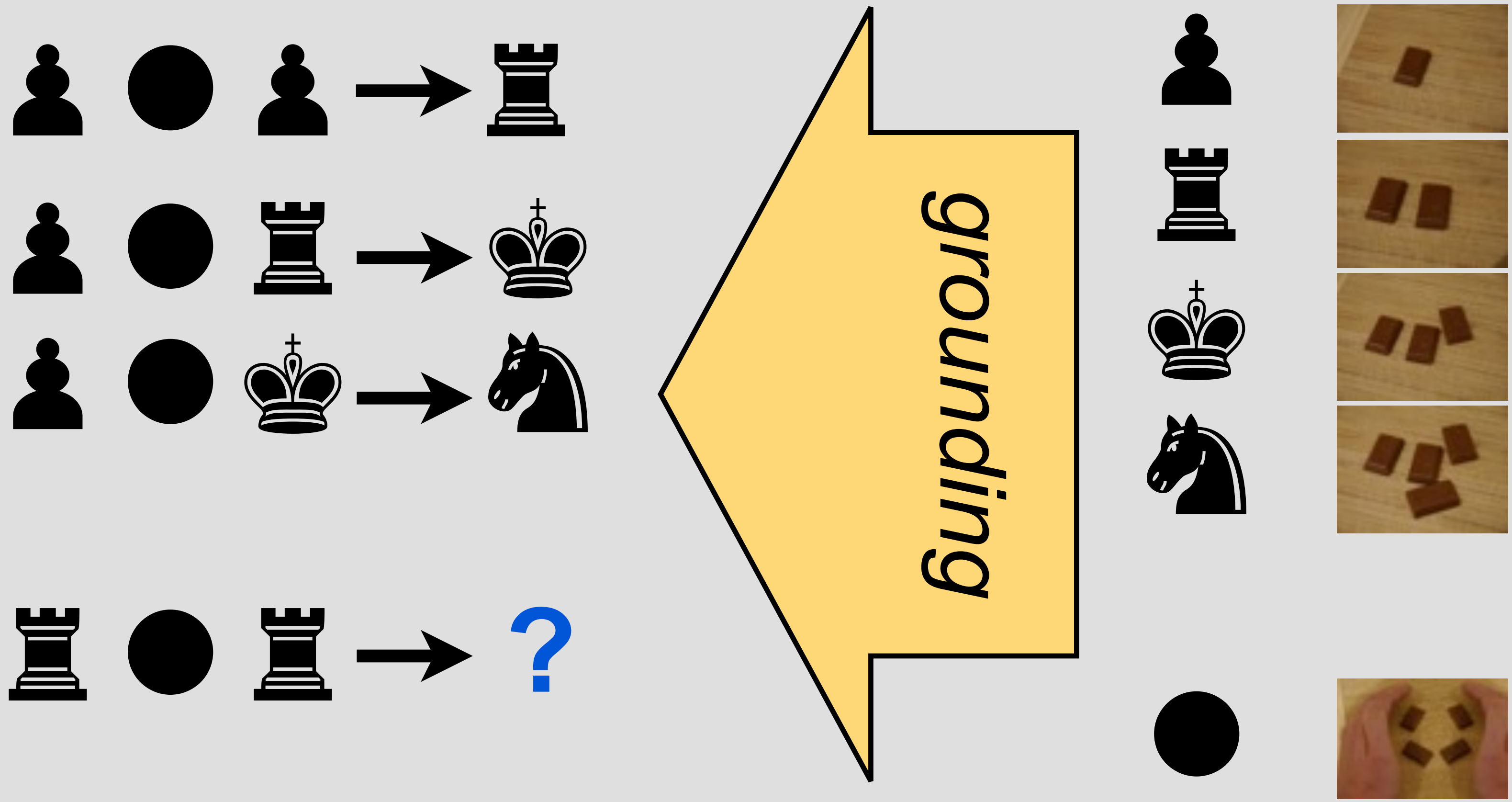
One example of the benefit of grounding



One example of the benefit of grounding



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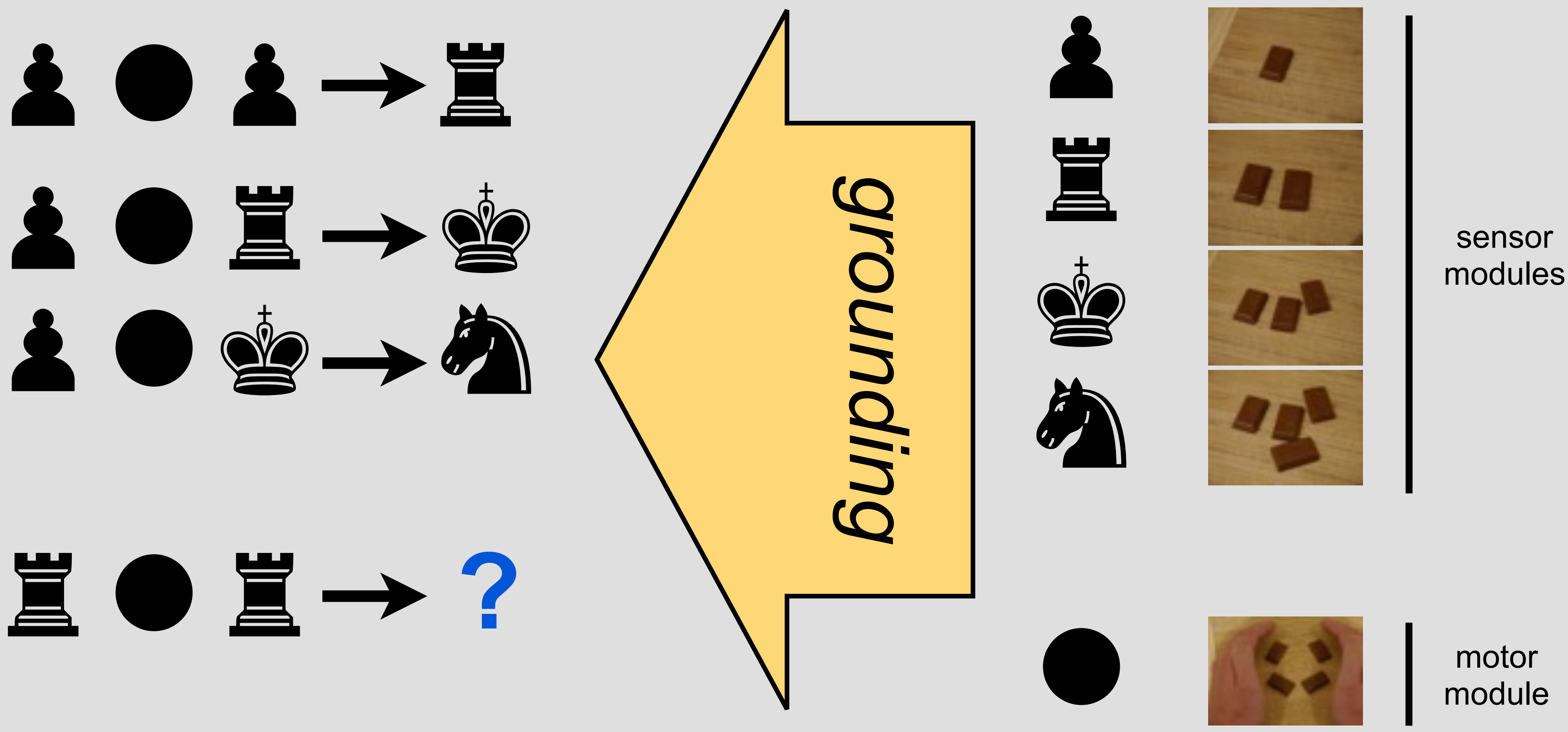

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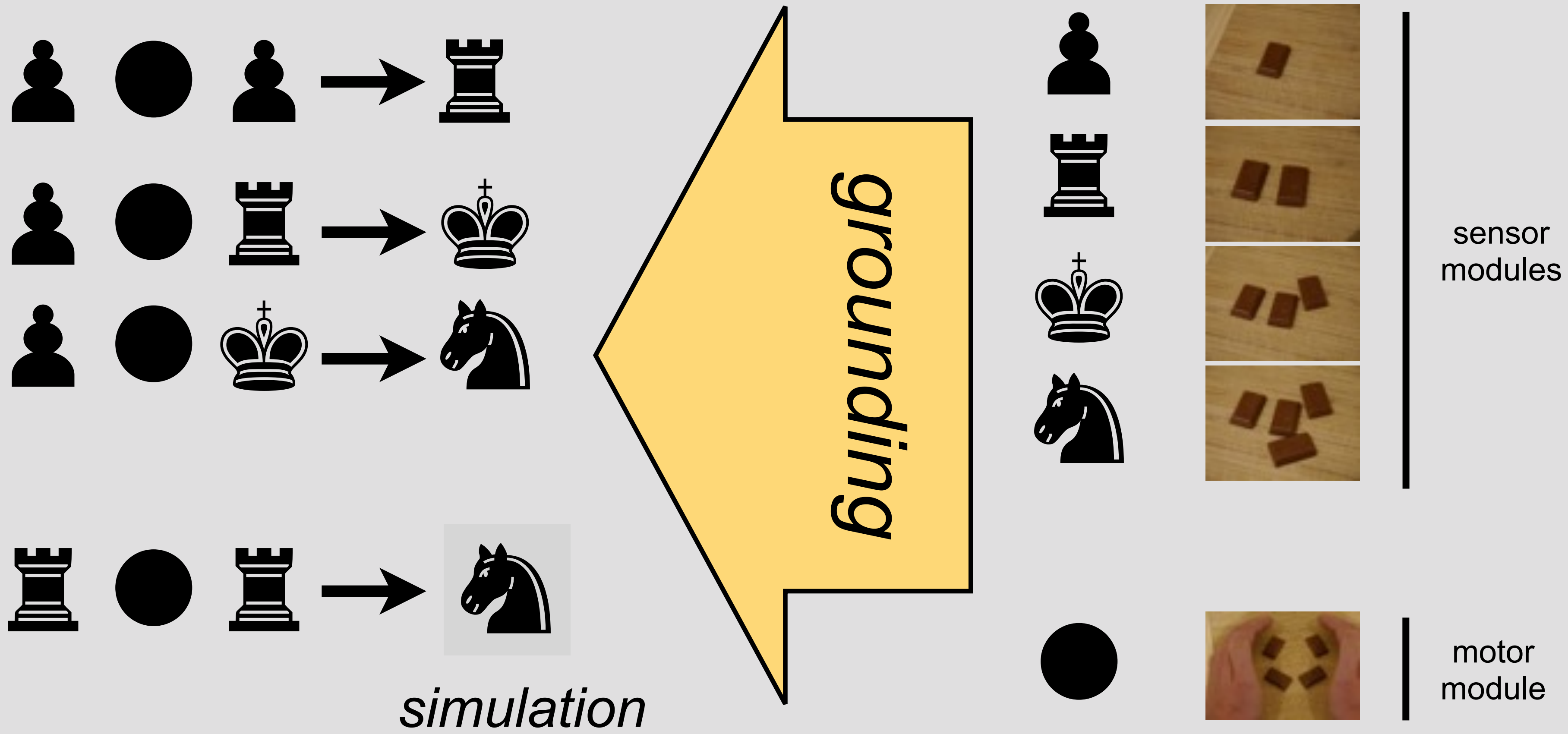


One example of the benefit of grounding

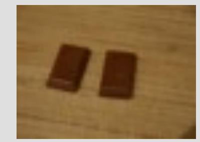
1 + 1 → 2

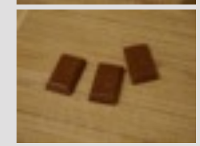
1 + 2 → 3

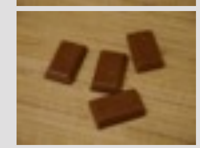
1 + 3 → 4

2 + 2 → **4**

1 

2 

3 

4 

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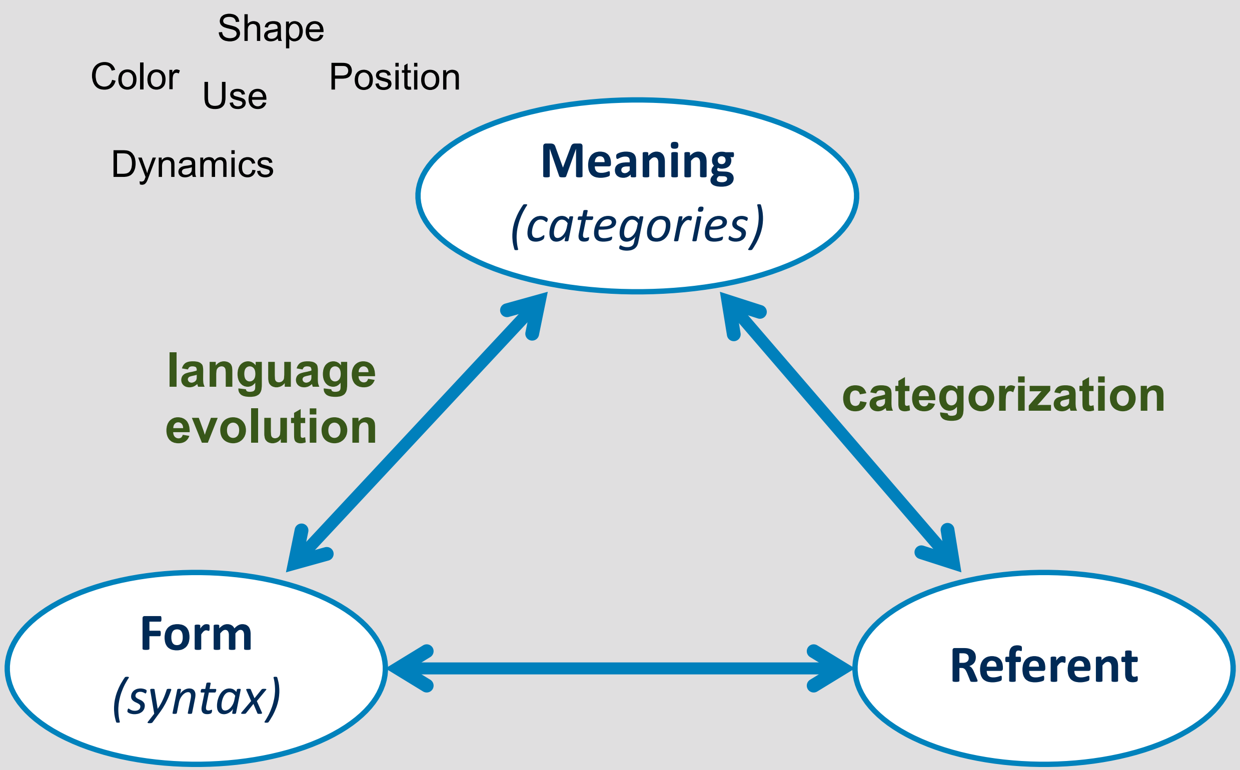
Semiotic Triangle



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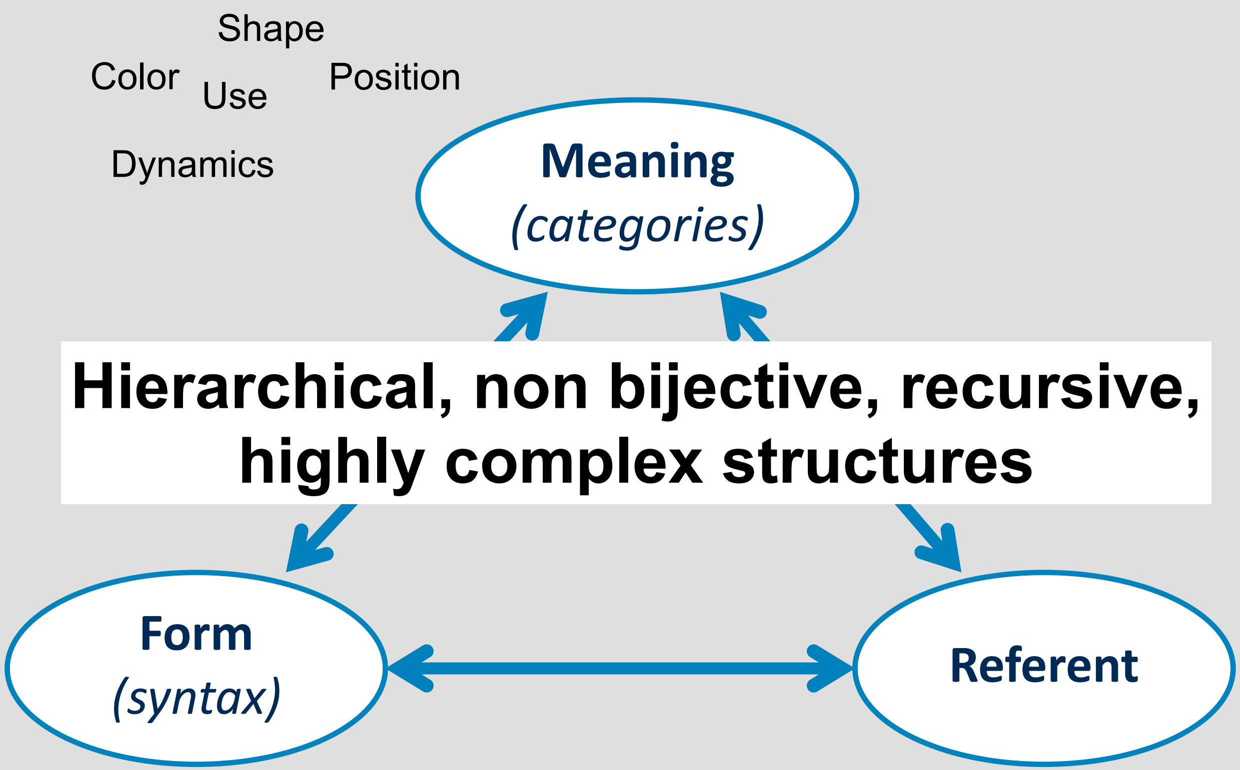


Evolving complex structures

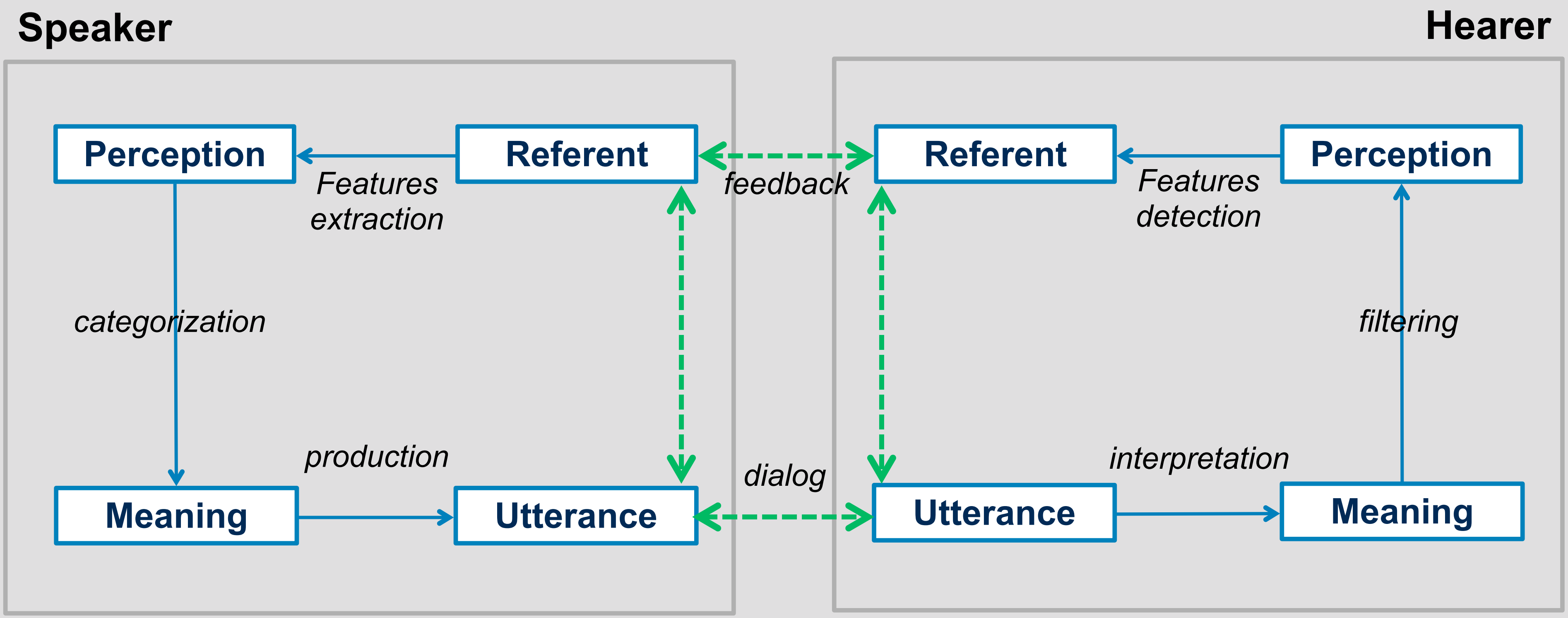
"[...] *evolution by cumulative [...] selection is the only theory we know of that is in principle capable of explaining the existence of organized complexity.*"

The Blind Watchmaker, R.Dawkins

Talking heads experiment

Luc Steel, Frédéric Kaplan, “*Bootstrapping grounded word semantics*”, Linguistic evolution through language acquisition: formal and computational models, 1999 Cambridge University Press

Guessing game



from Luc Steel, “Language games for autonomous robots”, IEEE INTELLIGENT SYSTEMS 2001 vol 16

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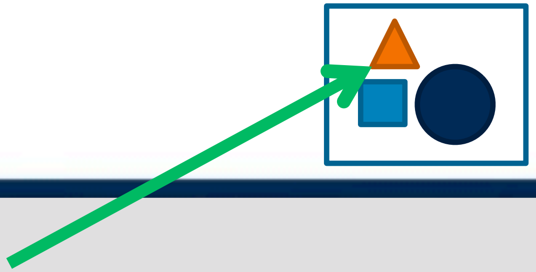

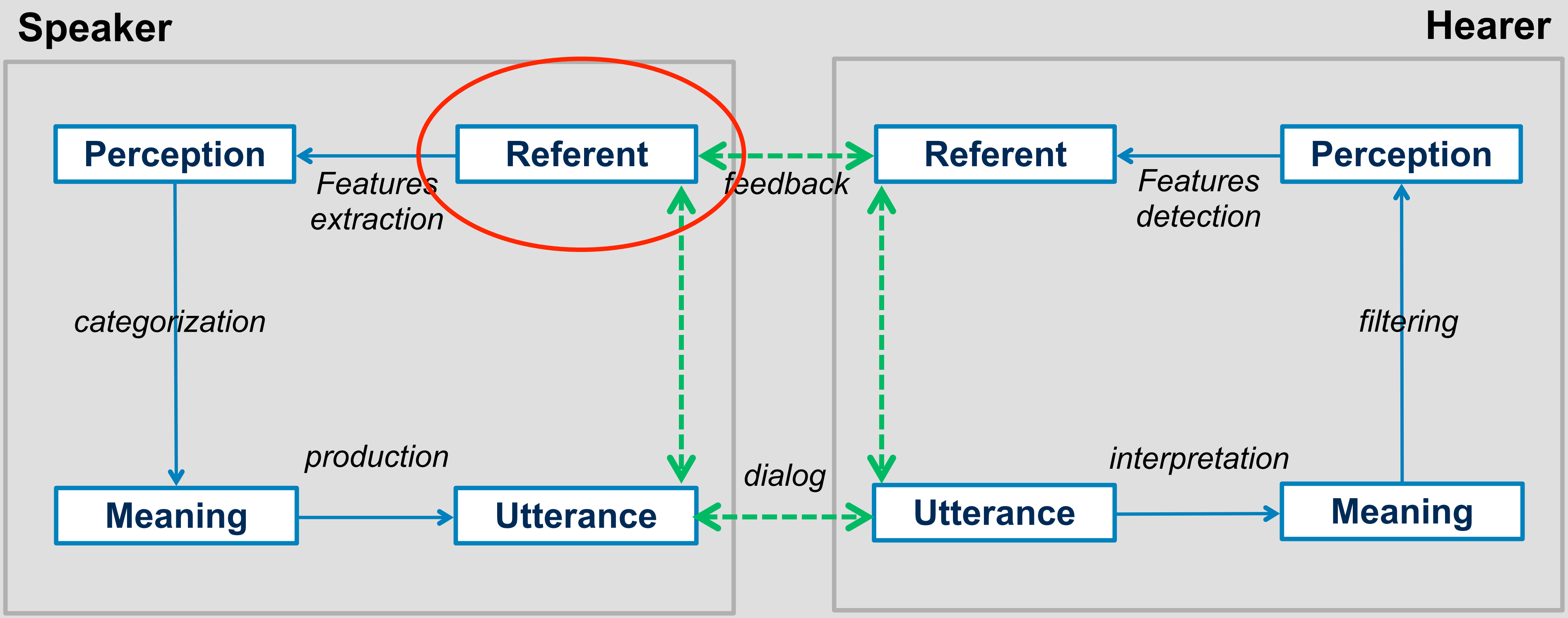

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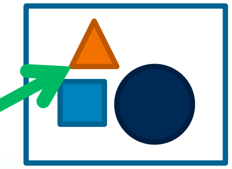

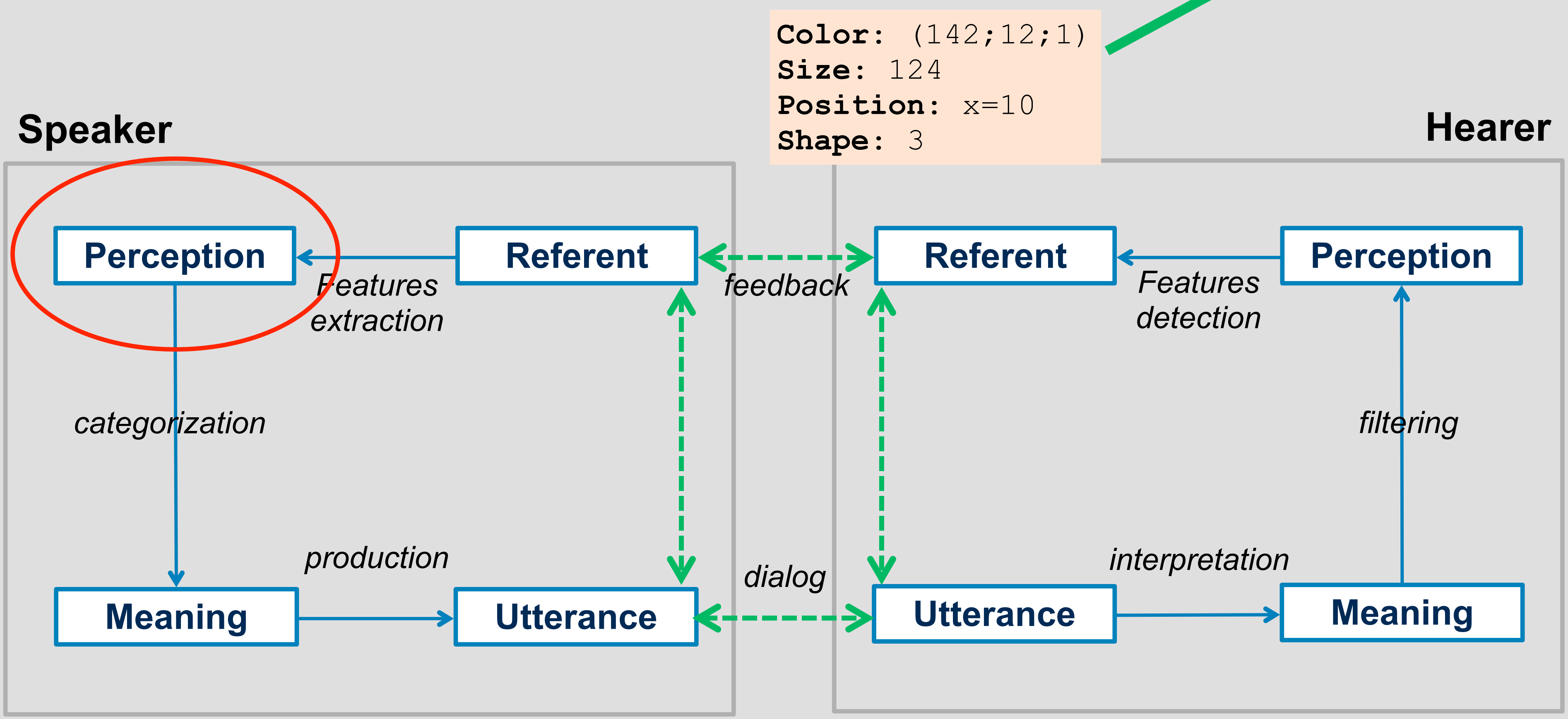

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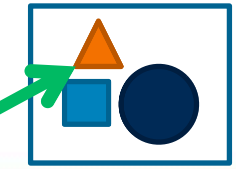

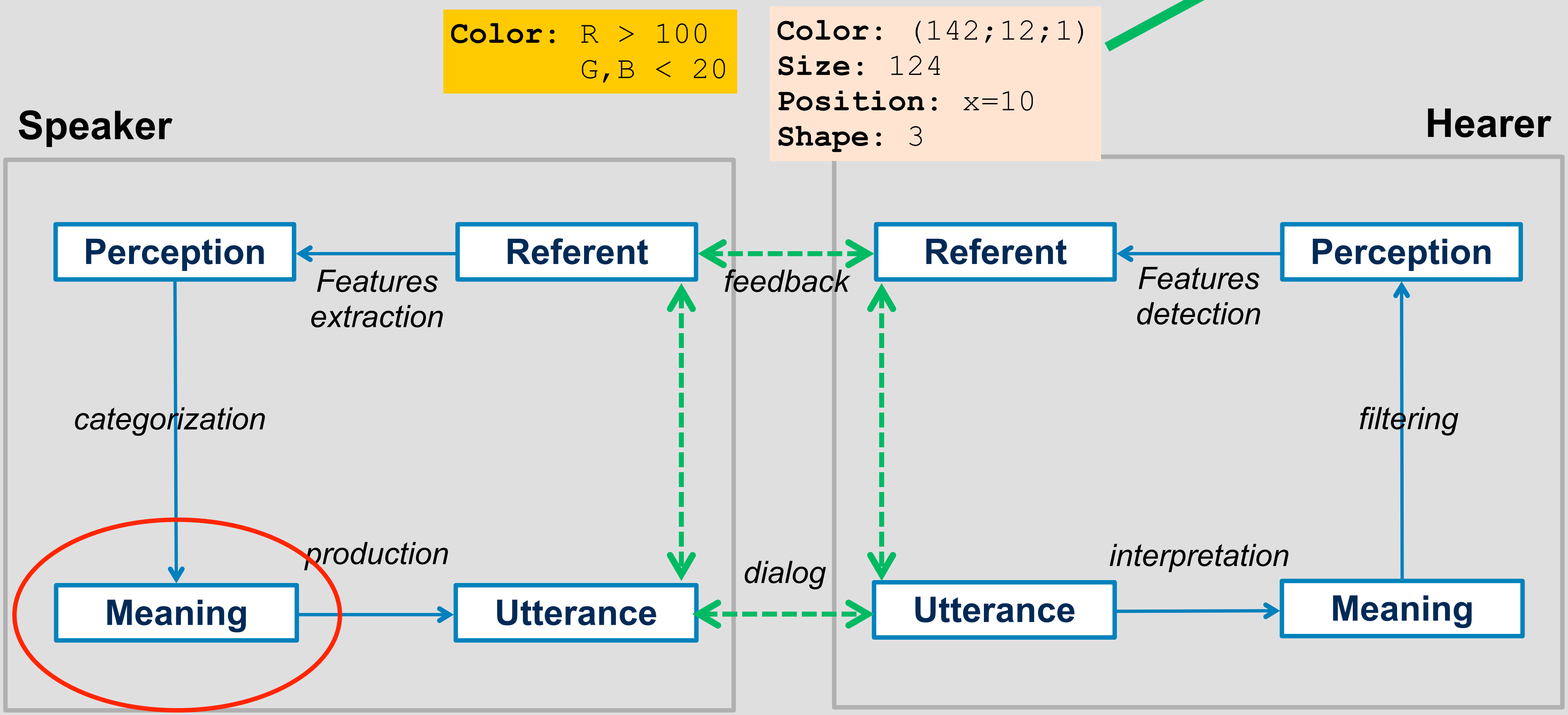

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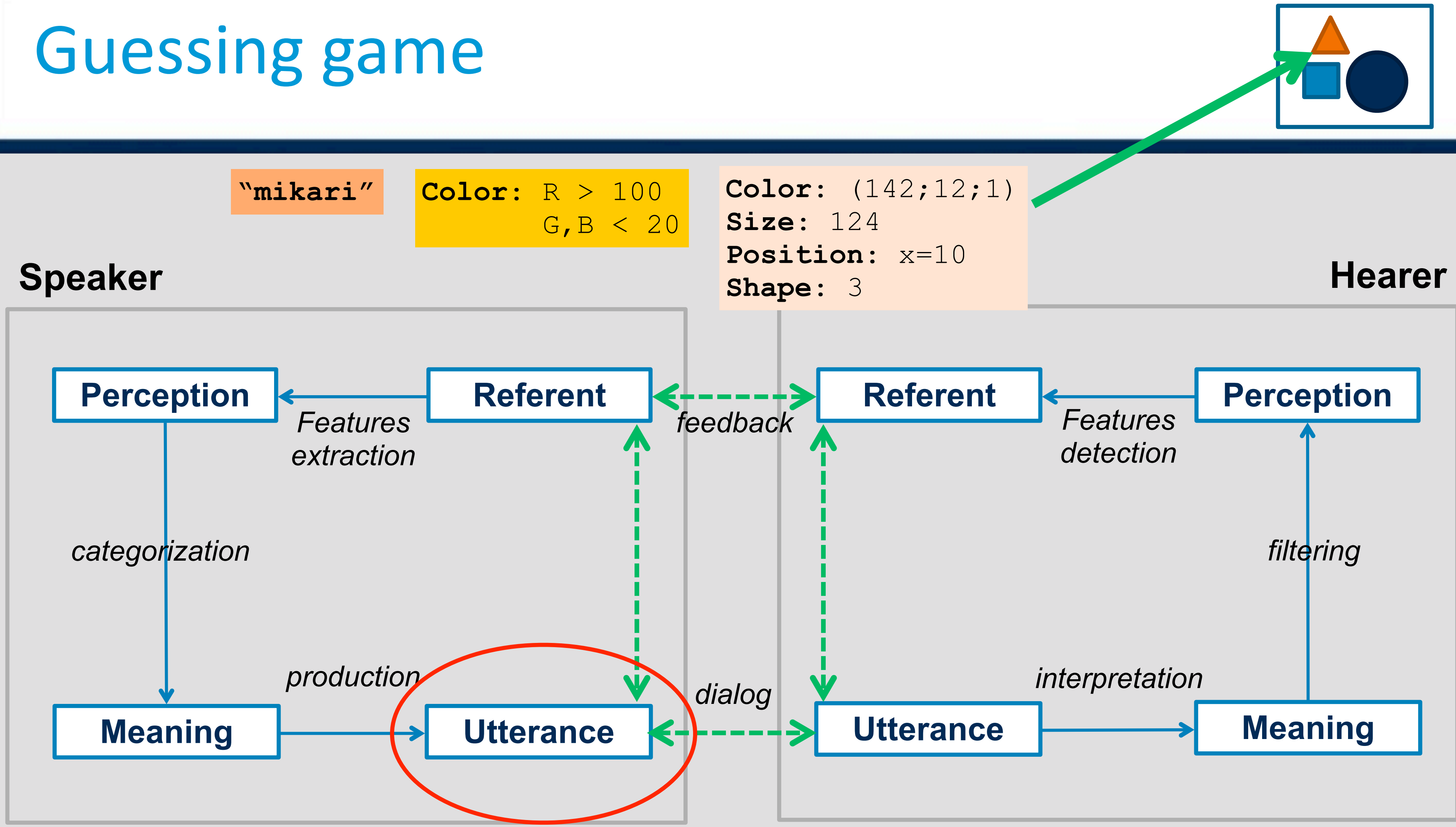

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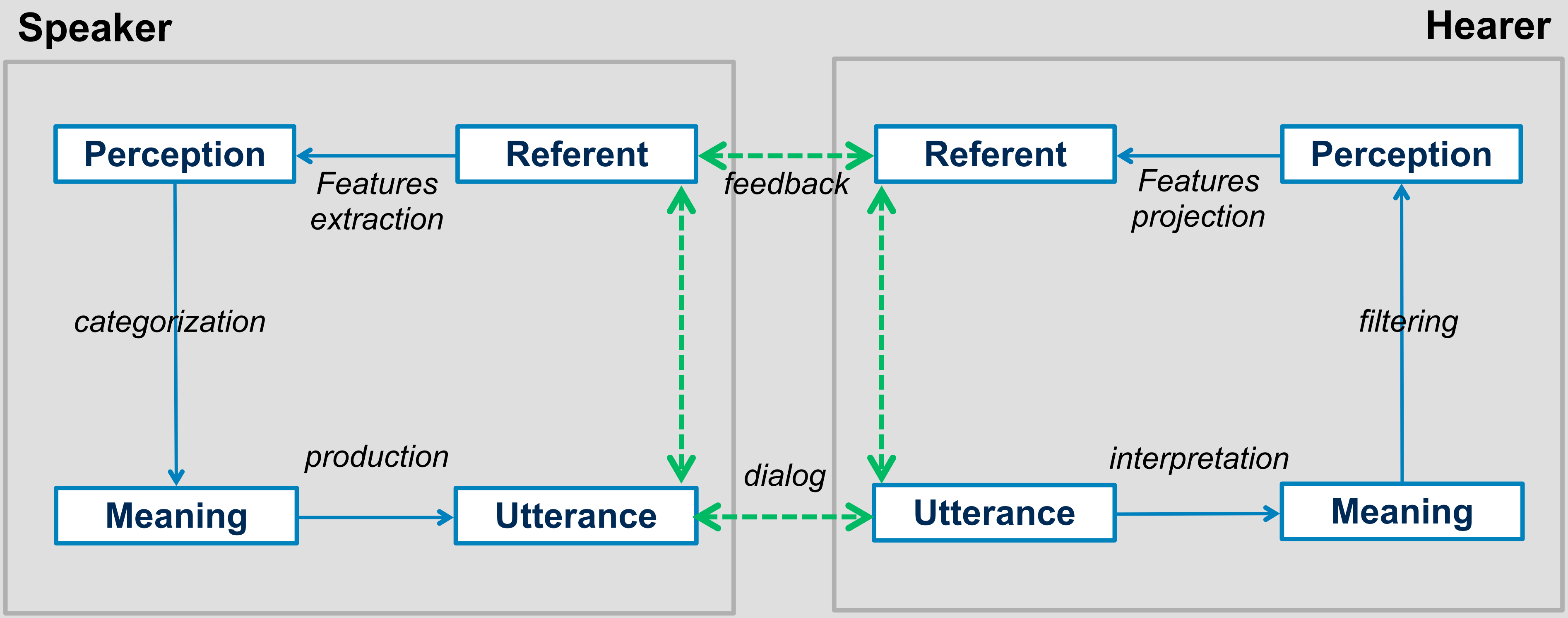

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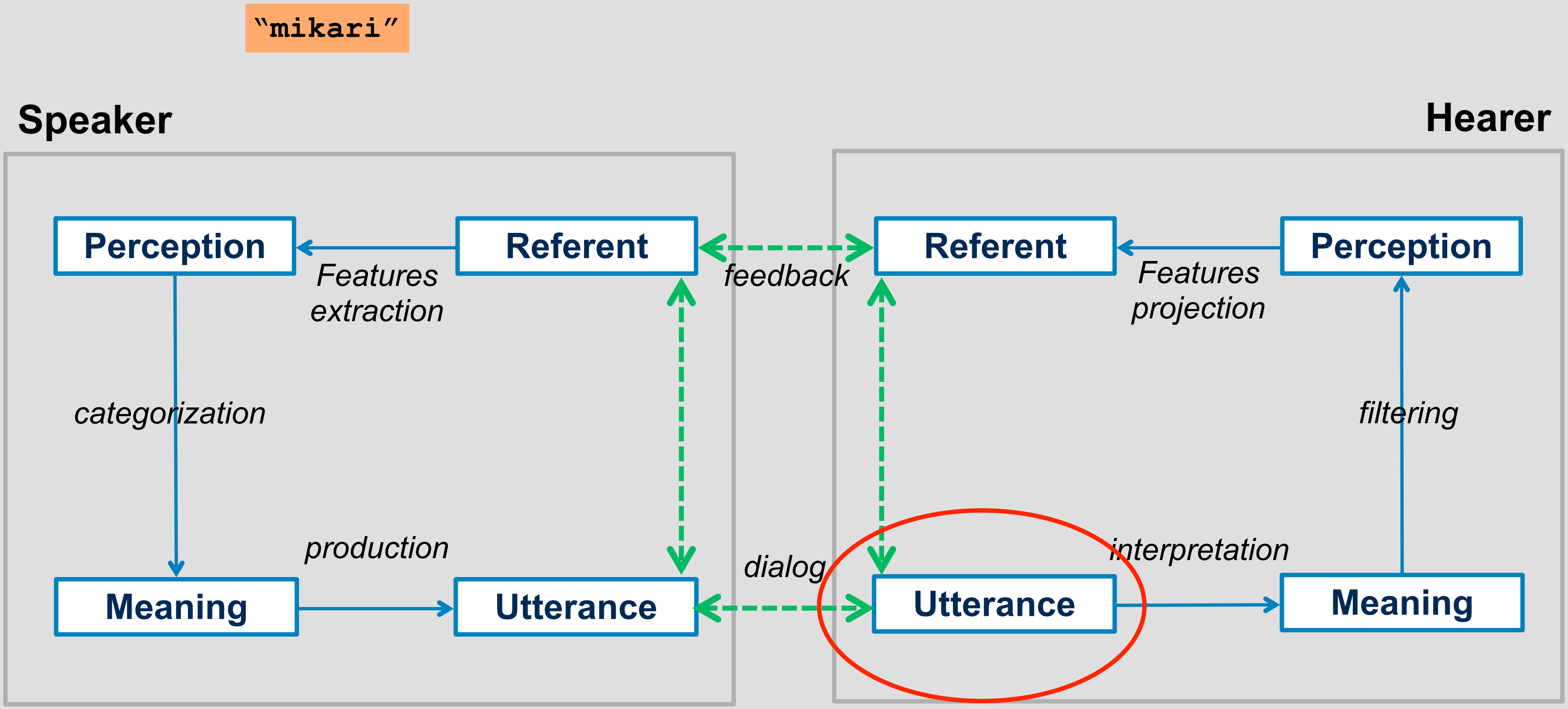

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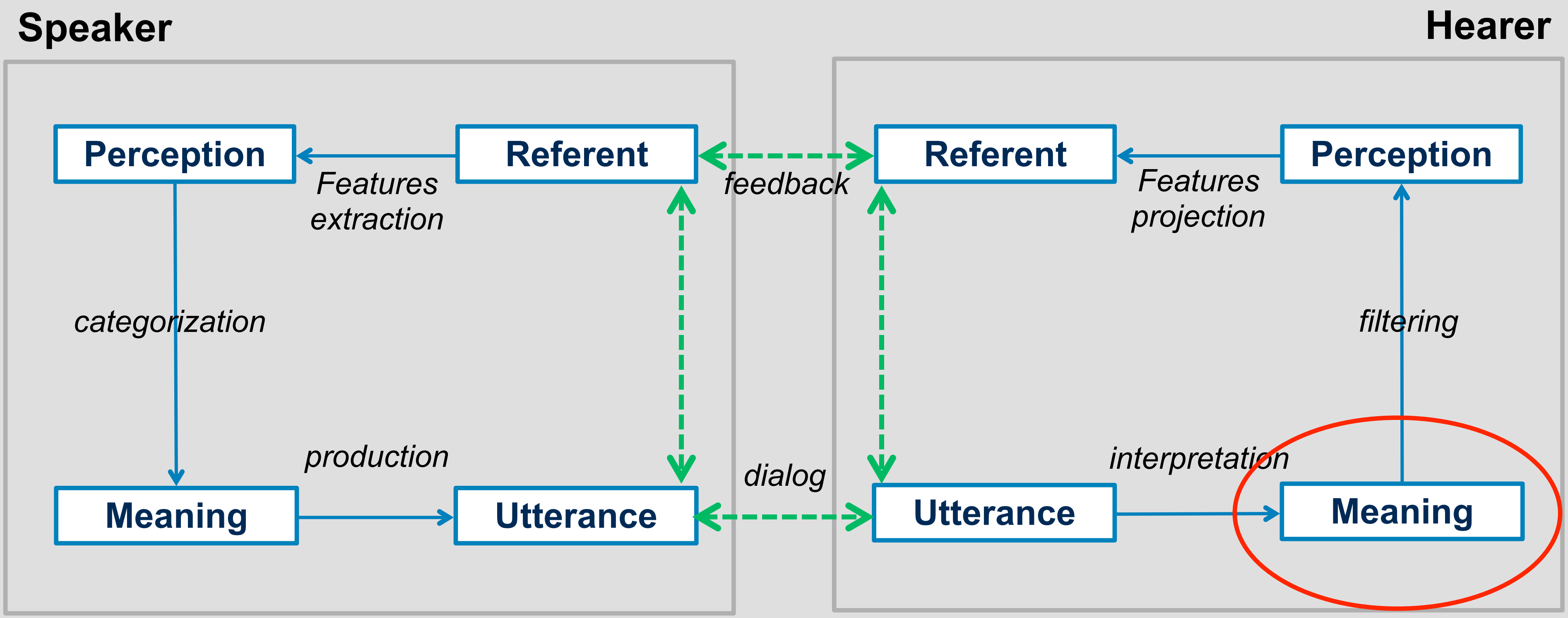
Guessing game

"mikari"

Position: x > 5



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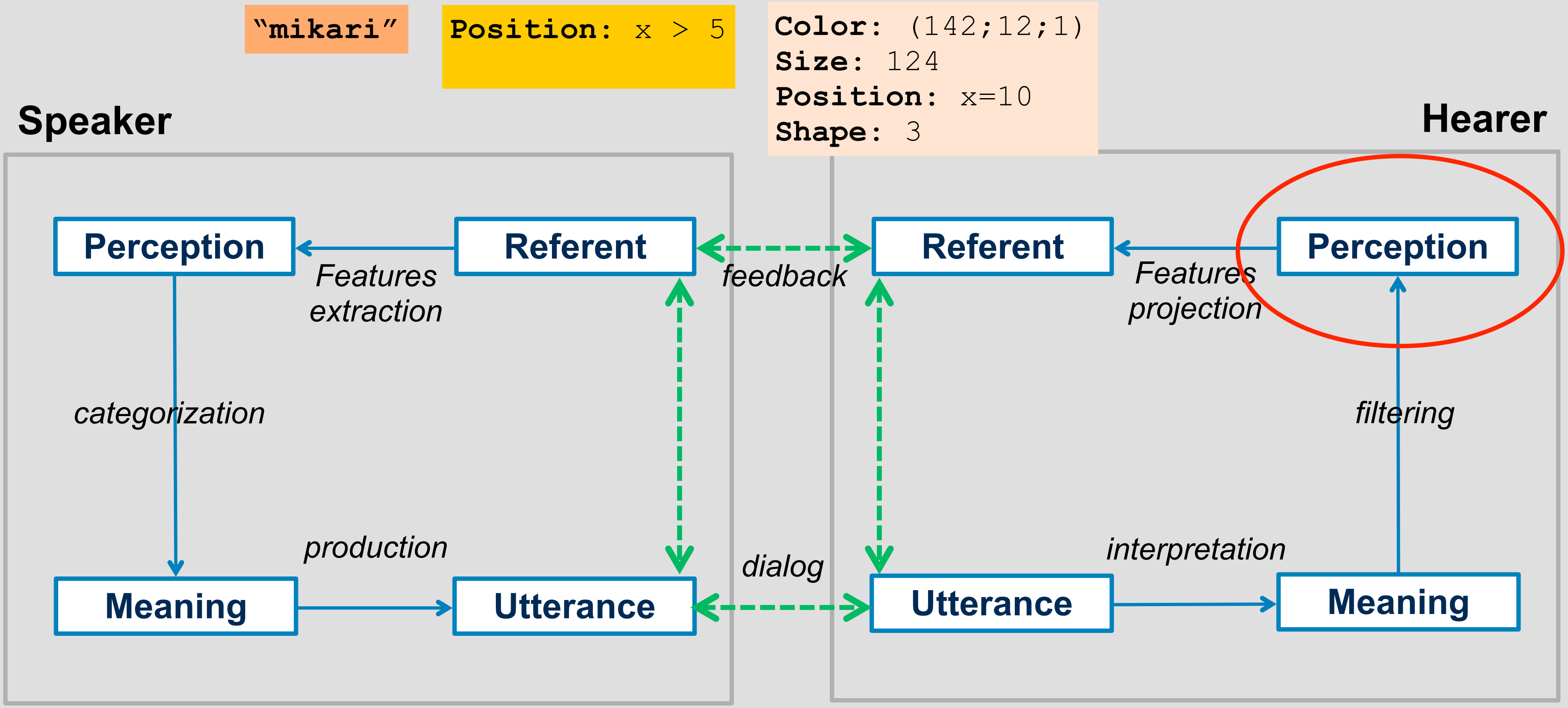

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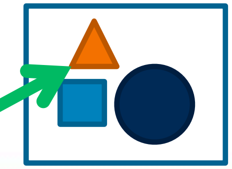

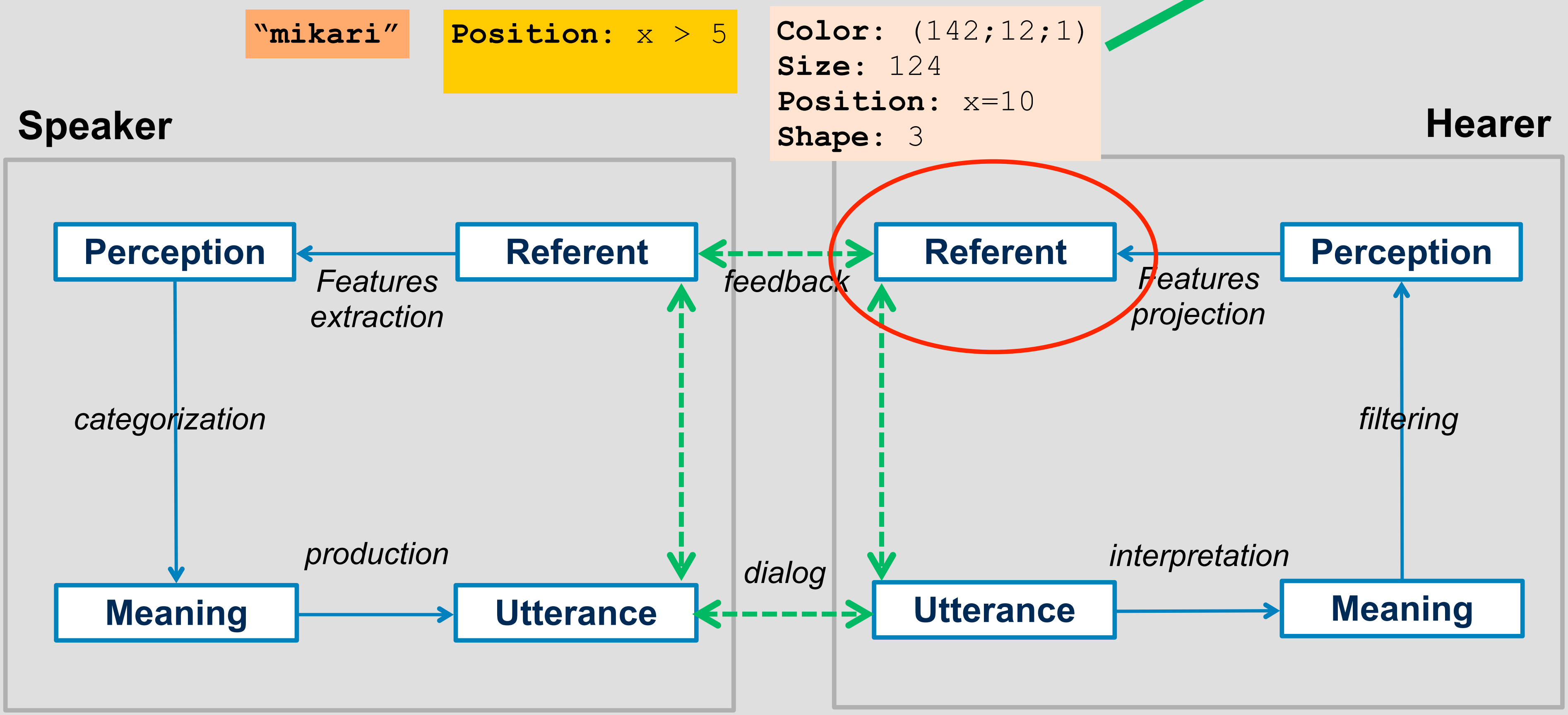

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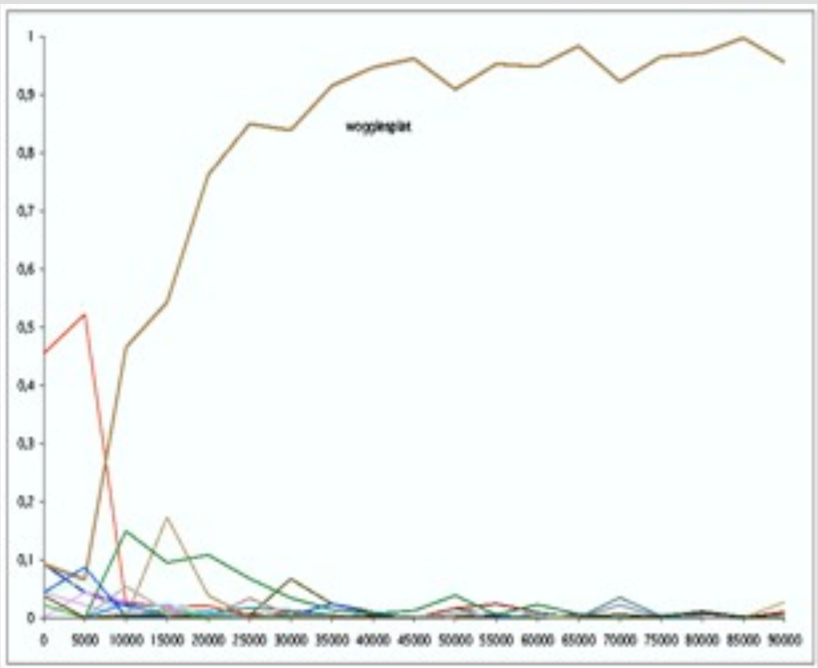
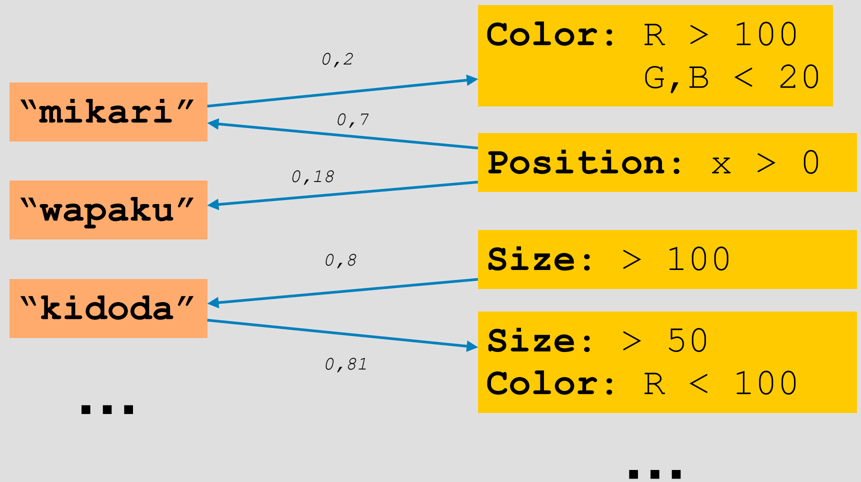
Grounded dynamics





After a few thousand iterations, agents **synchronize** a **shared grounded** lexicon to describe their world.

from Luc Steel, "The emergence and evolution of linguistic structure: from lexical to grammatical communication systems", Connection science 2005

Why is it an important experiment?

- Symbols are **socially** grounded: the lexicon is shared
- Symbols are grounded in the **environment**
- Symbols are grounded in the **task** (here, the game)

Next step: grounding grammar

Grammar: set of conventionalized strategies to disambiguate

"John gives a ball to Mary" → *give* **???** *John* *ball* *Mary*

from Generative to Construction Grammar

Generative Grammars (Chomsky)

S ⇒ NP + VP

NP ⇒ N

NP ⇒ Det + N

VP ⇒ V

VP ⇒ V + NP

...

from Generative to Construction Grammar

Generative Grammars (Chomsky)

Combinatorial explosion + Syntax only

S ⇒ NP + VP

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from Generative to Construction Grammar

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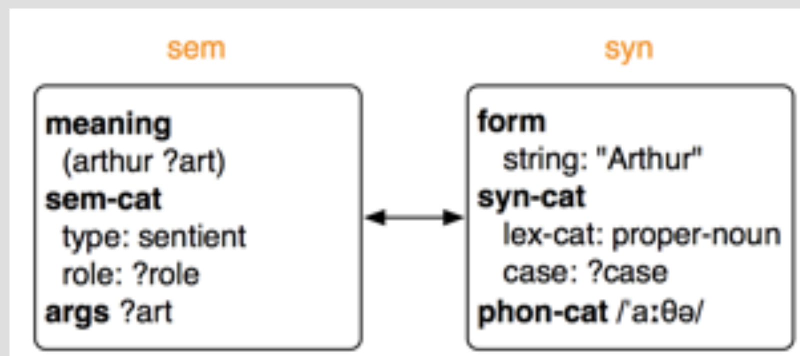
VP ⇒ V

VP ⇒ V + NP

...

N



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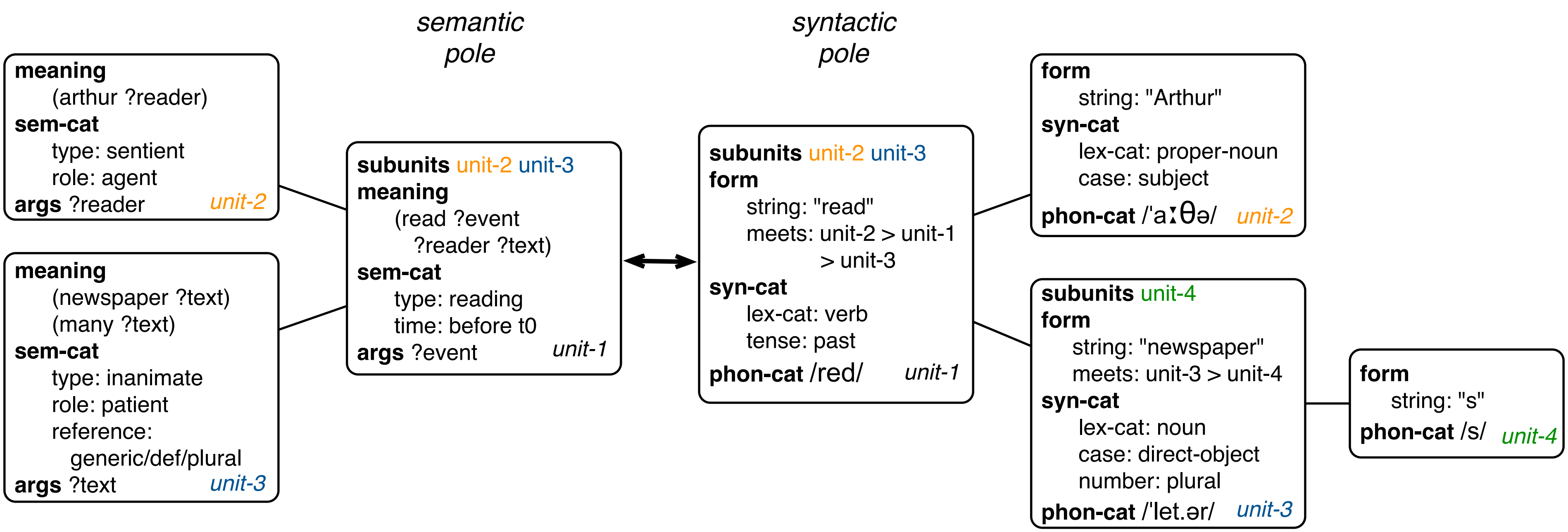
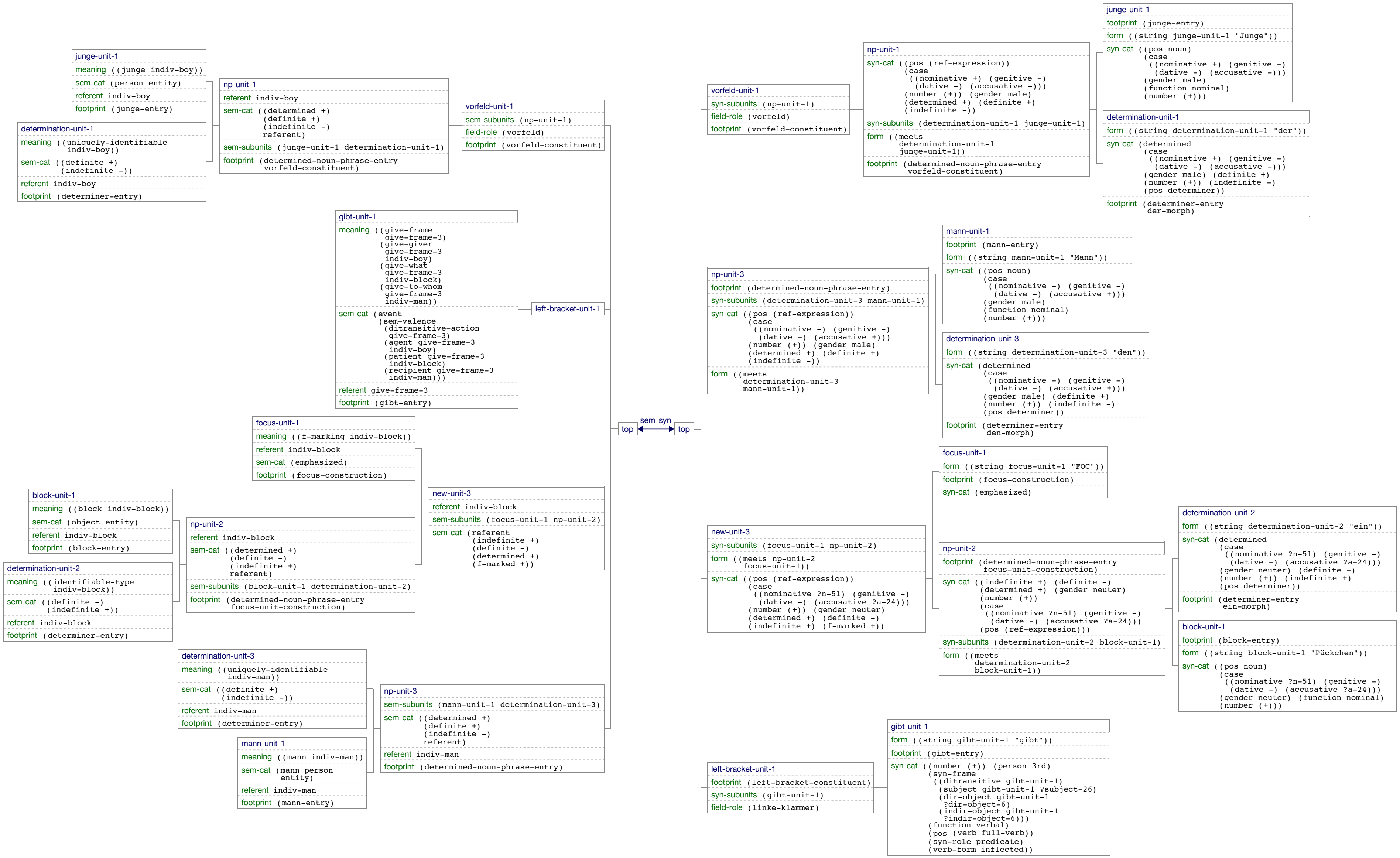
Fluid Construction Grammar

Arthur read newspapers



from Katrien Beuls, “A first encounter with Fluid Construction Grammar”,
UPF TRL PhD seminar, 04 Mar 13

... and 2 more



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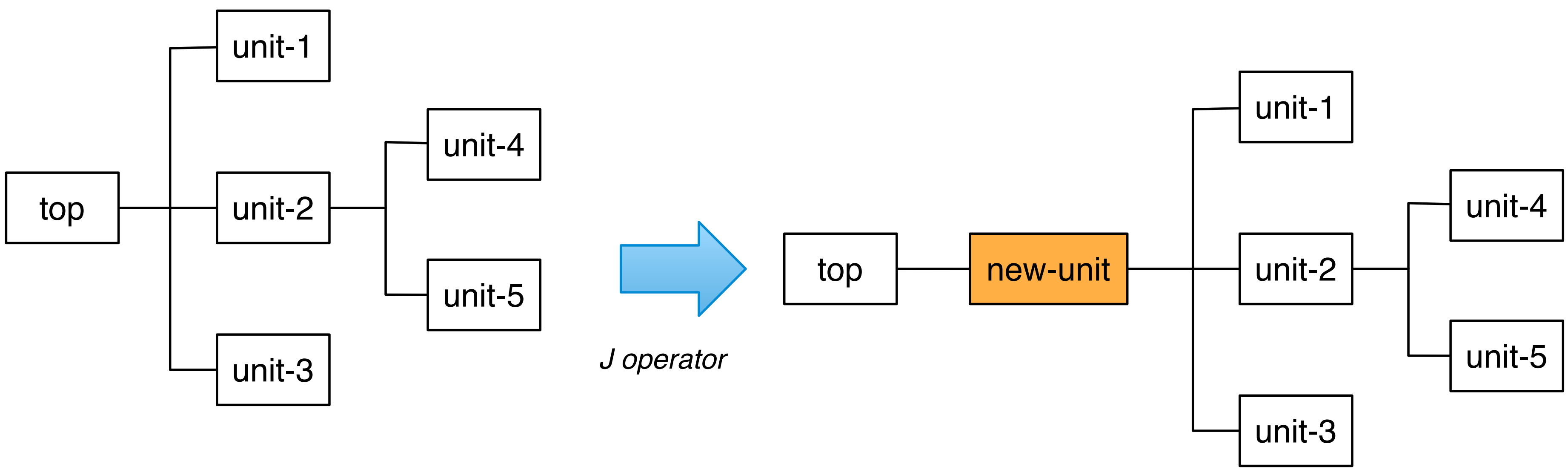
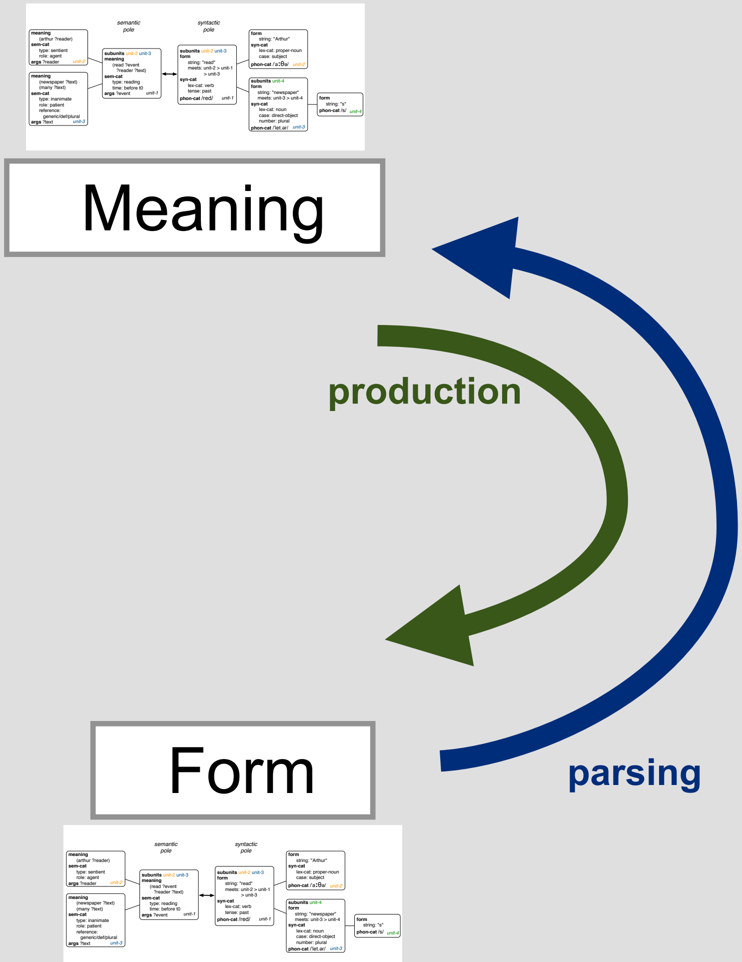
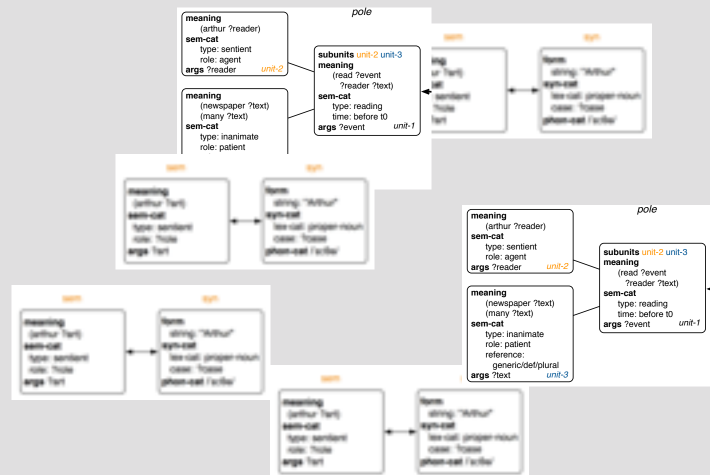
Operators to perform unit transformations



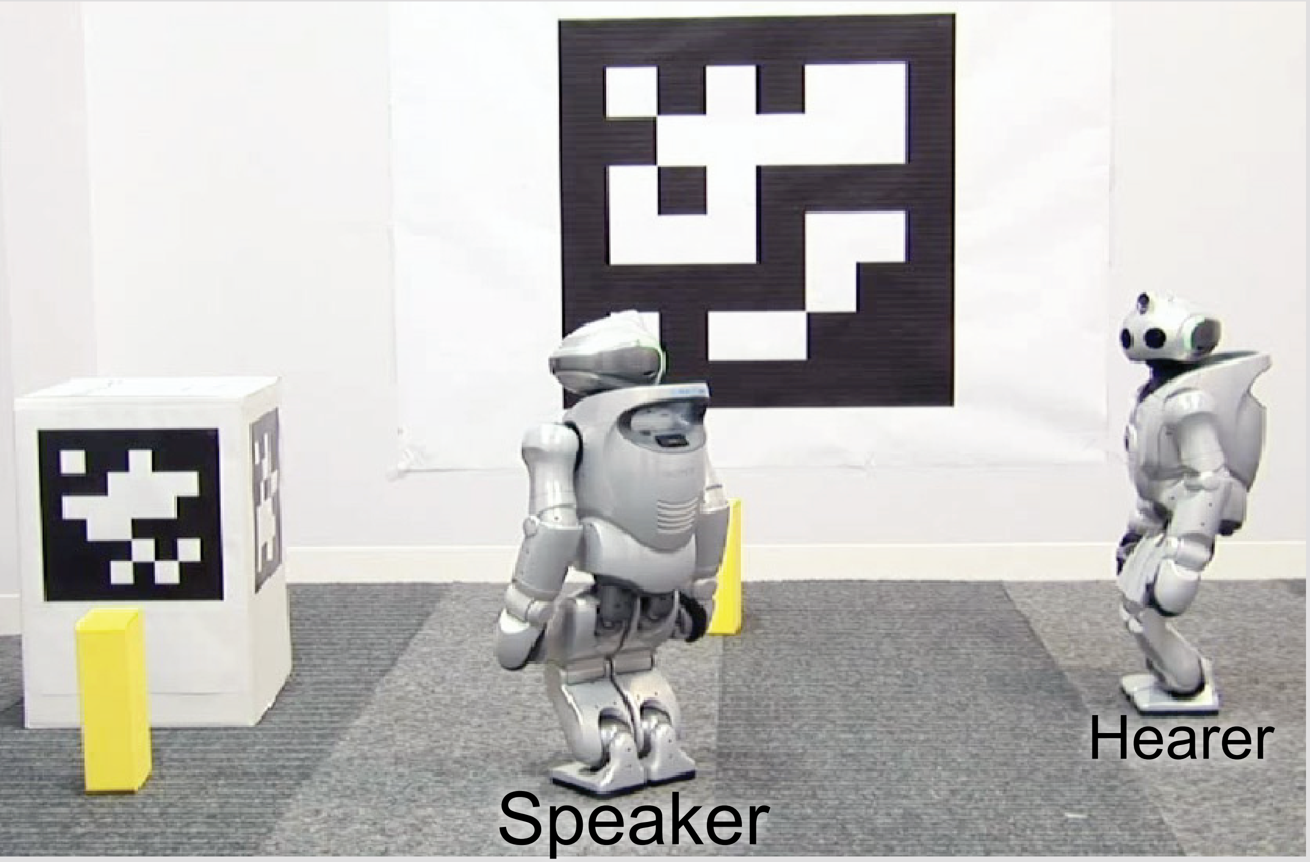
FCG: Analogy with chemistry

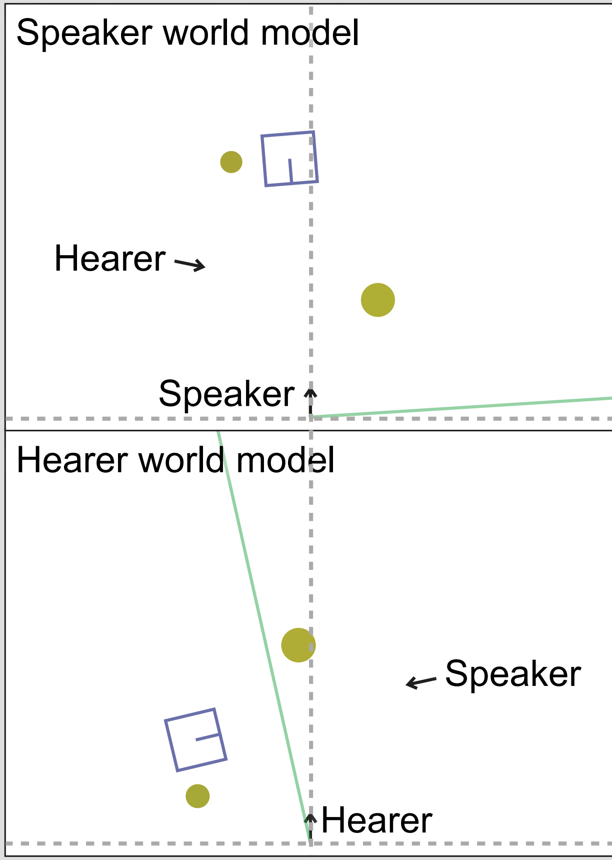


complex "soup" of potentially relevant constructions



Grounding spatial grammatical conventions





from Spranger,M., Pauw, S., Loetzsch, M., and Steels, L. "Open ended procedural semantics", Language grounding in robots. Springer, New-York

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Language development stages

FCG and similar computational models of construction grammars are good candidates to account for **stages of linguistic competences**, in a **usage-based approach** of language learning:

- Holophrases
- Word combinations
- Pivot Schemas
- Item-based constructions
- Abstract constructions

from Tomasello, 2005

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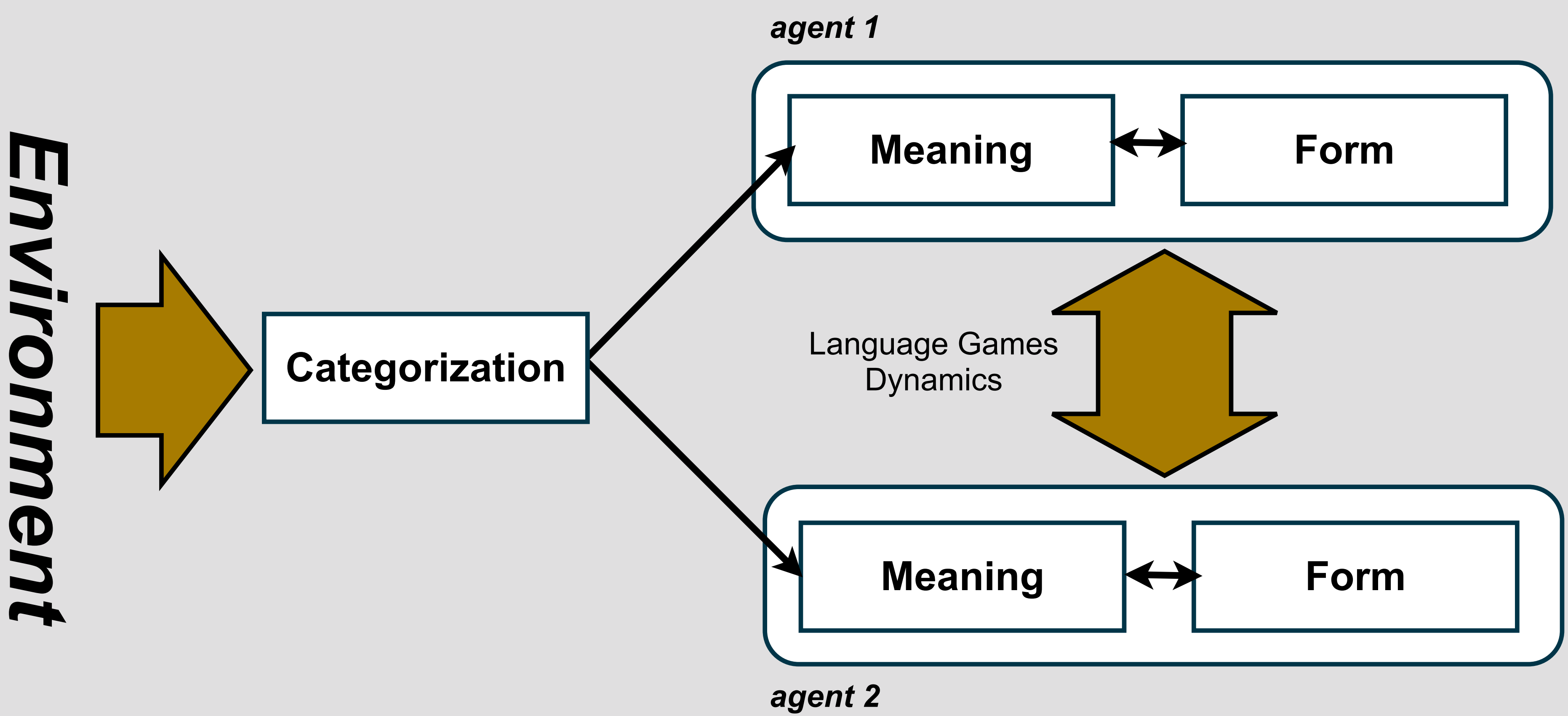
What comes next?



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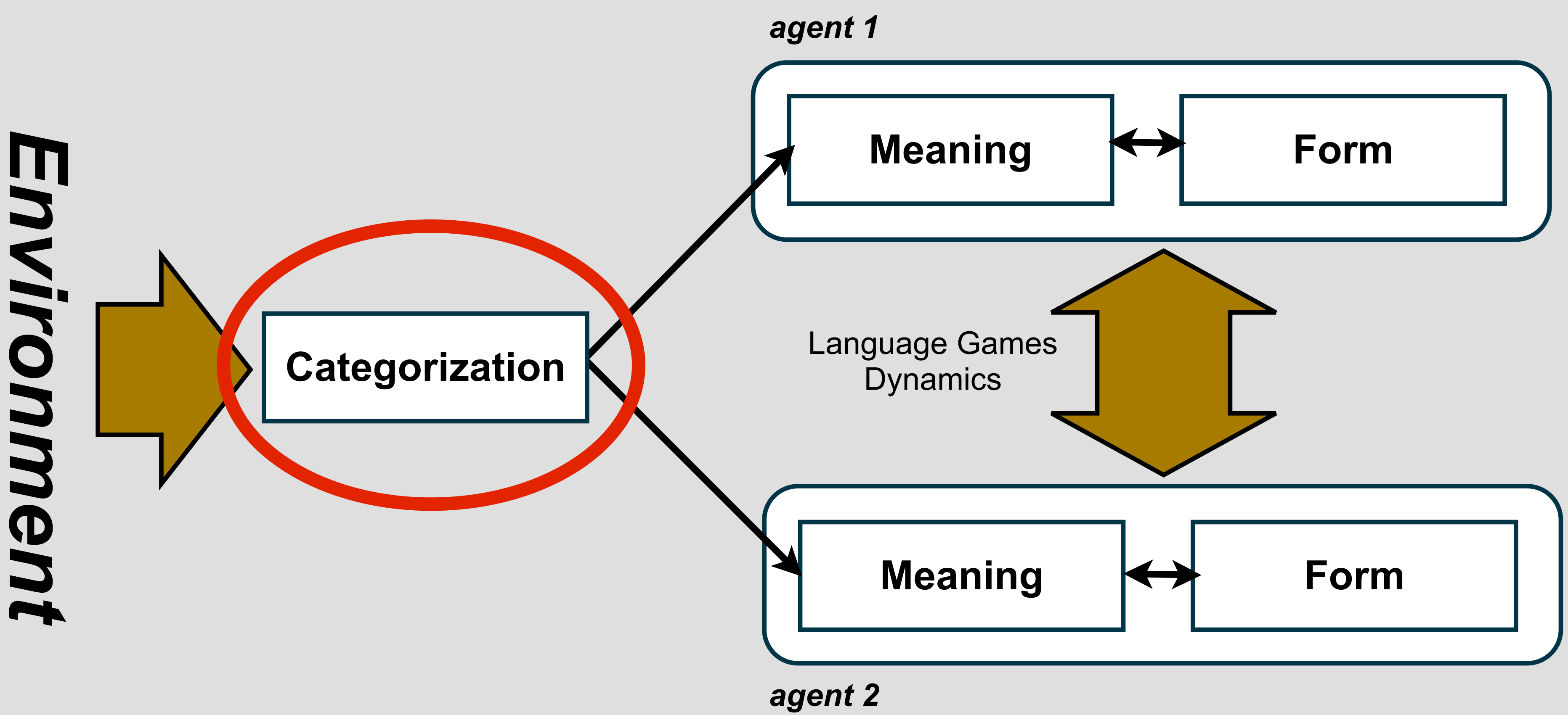

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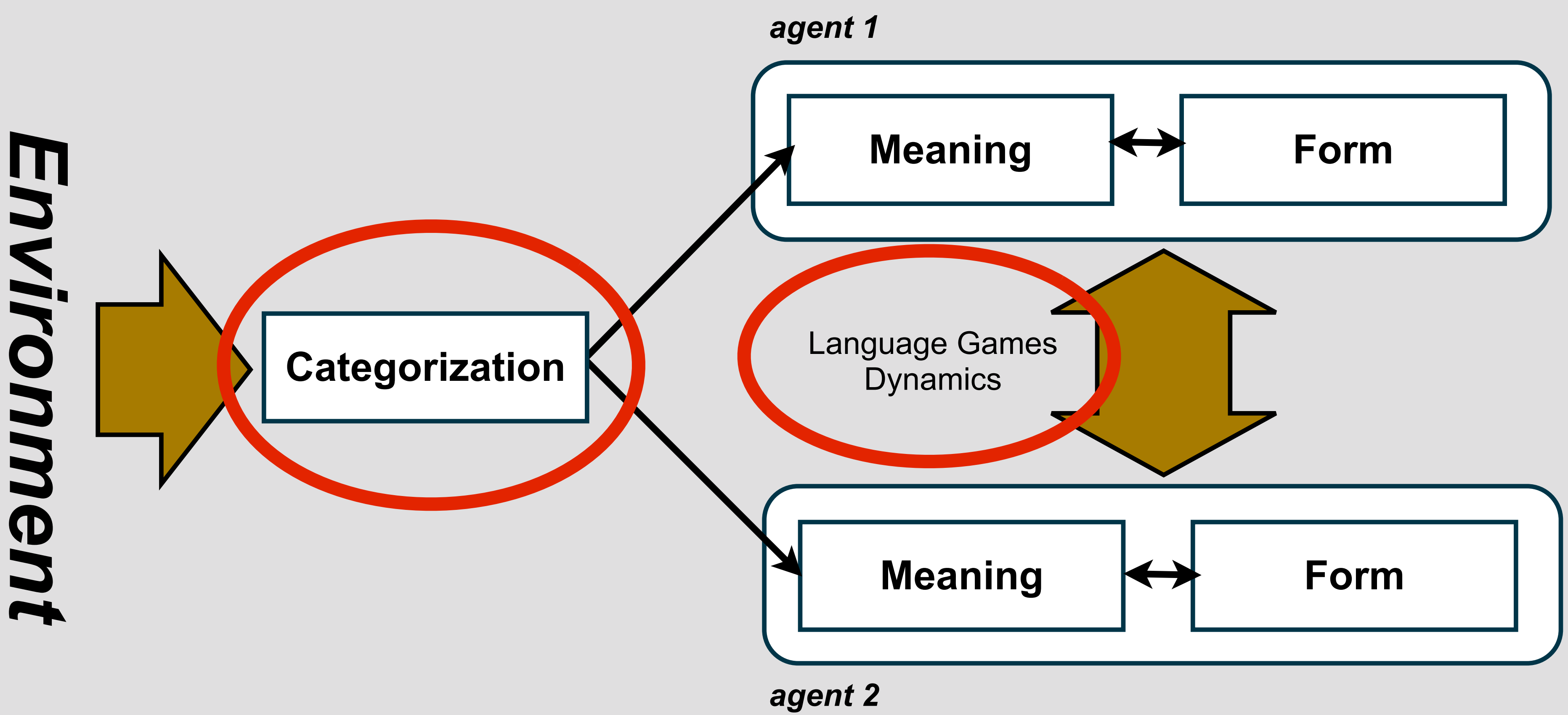


Developmental Robotics

Focus on the learning mechanisms

Not the end result

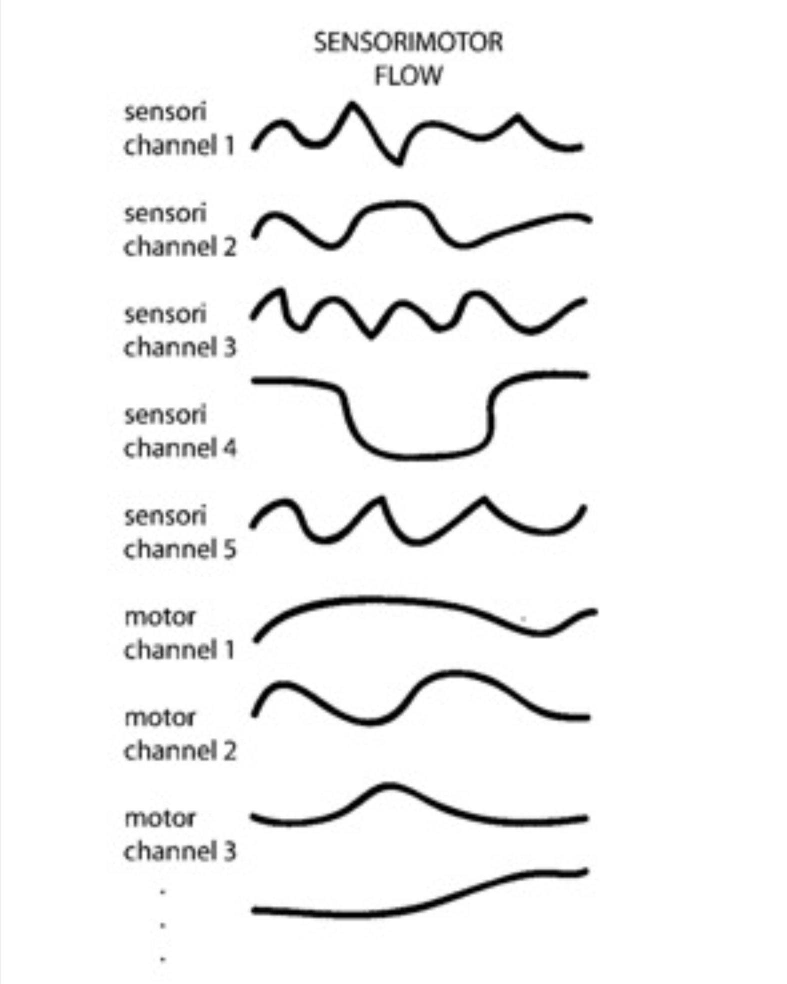
... but the process

Key aspects of the developmental approach

- **Grounded** semantics
- **Staged** development => previous stages help to build the next.
- **Dynamic** systems, Life-long learning

Categorization

What is it like to be a robot?



"The Blooming, buzzing confusion"

William James

Scaffolding knowledge through interaction

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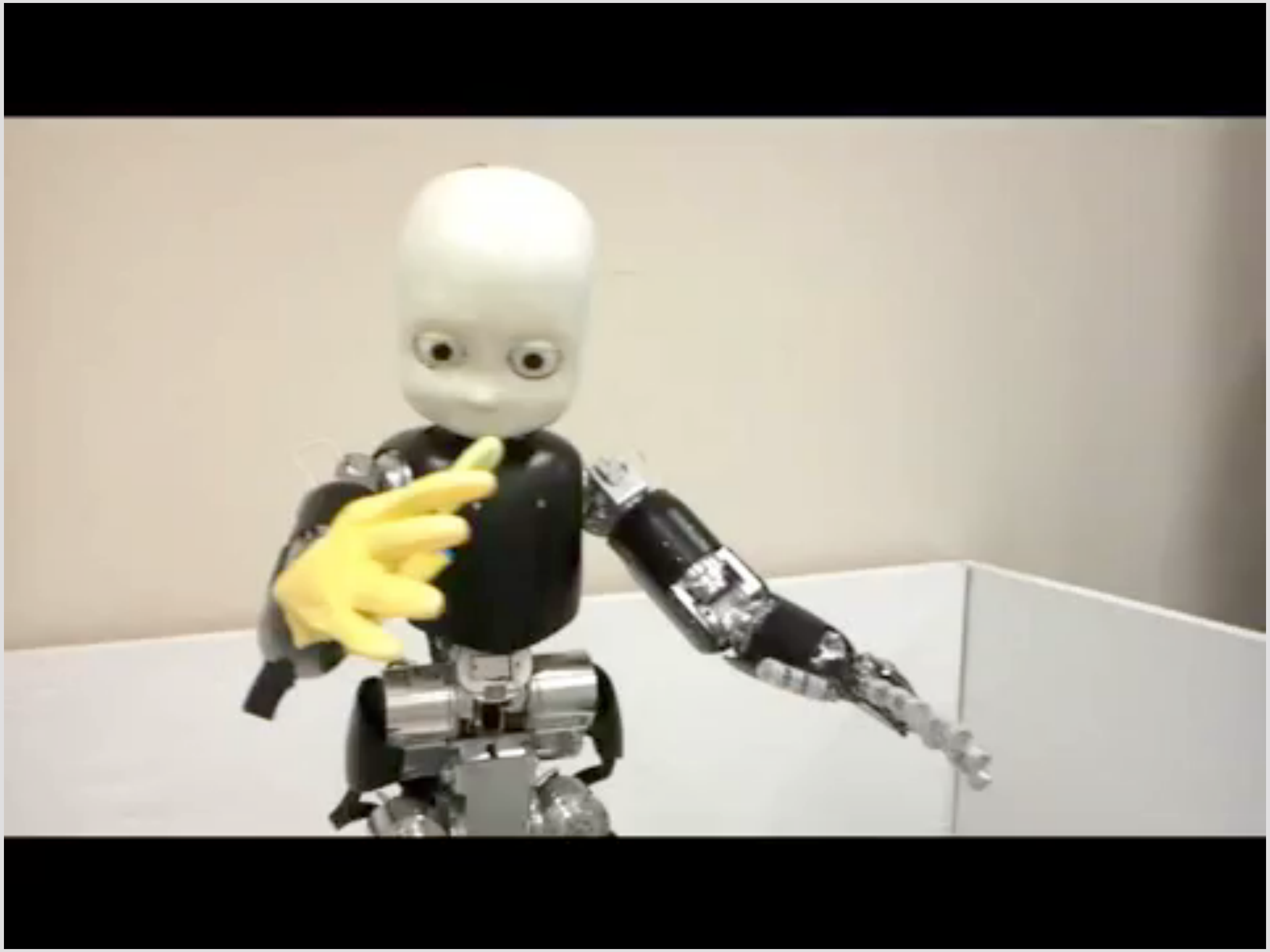
Learning its own body



Ref: **University of Illinois at Urbana-Champaign**

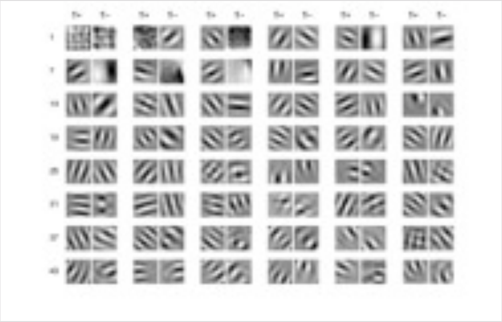
Learning its own body

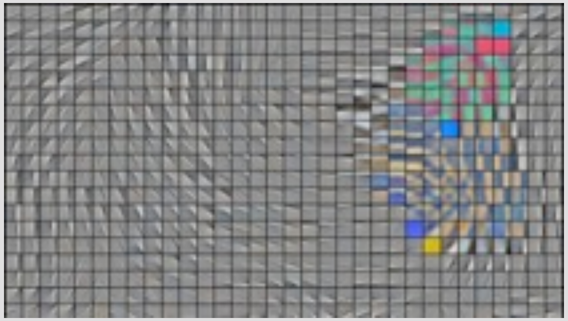
Ref: **Sony CSL**

Low level visual and audio pattern extraction

- **Avoid biases as much as possible in the nature and structure of relevant perceptual data for the robot.**

- **Deep Learning**: hierarchical neural approaches in general
- **Slow Feature Analysis**: layered approaches to build up structure
- **Multi-modal cross-correlation** extraction





- Quoc V Le, Rajat Monga, Matthieu Devin, Greg Corrado, Kai Chen, Marc'Aurelio Ranzato, Jeff Dean & Andrew Y Ng. **Building highlevel features using large scale unsupervised learning**. arXiv preprint arXiv:1112.6209, 2011
- Yoshua Bengio. **Learning deep architectures for AI**. Foundations and Trends in Machine Learning, vol. 2, no. 1, pages 1–127, 2009
- Sven Behnke. **Hierarchical neural networks for image interpretation**, volume 2766. Springer, 2003
- Laurenz Wiskott & Terrence J Sejnowski. **Slow feature analysis: Unsupervised learning of invariances**. Neural computation, vol. 14, no. 4, pages 715–770, 2002

Sensorimotor conceptualization

- **Gather spatiotemporal correlations into conceptual first level categories.**

- **Proto-object** extraction
- Simple **motor skills schemata**
- Simple **causality, naïve physics**

=> Active Learning

- D.H. Rakison & L.M. Oakes. **Early category and concept development: Making sense of the blooming, buzzing confusion**. Oxford University Press, USA, 2003
- Francesco Orabona, Giorgio Metta & Giulio Sandini. **A proto-object based visual attention model**. Attention in cognitive systems. Theories and systems from an interdisciplinary viewpoint, pages 198–215, 2007
- Ryunosuke Nishimoto, Jun Namikawa & Jun Tani. **Learning multiple goal-directed actions through self-organization of a dynamic neural network model: A humanoid robot experiment**. Adaptive Behavior, vol. 16, no. 2-3, pages 166–181, 2008
- Paul Fitzpatrick, Giorgio Metta, Paul Fitzpatrick & Giorgio Metta. **Grounding vision through experimental manipulation**. Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, vol. 361, no. 1811, pages 2165–2185, 2003

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Joint Action

towards language games

Scaffolding knowledge through interaction

Some fundamental & open questions

- What is the role of **pointing**?
- What **simulators** do we run in our heads?
- How do we ground a **theory of mind**?
- What is the role of **emotions**?
- How does the system represent a **goal**?
- How do developmental **stages** unfold?
- How do we represent **fluid knowledge**?
- …

Curiosity & Intrinsic Motivation

What drives an autonomous system?

- ***Physiological needs*** *=> food, safety, …*
- ***Curiosity*** *=> intrinsic motivation*

Curiosity **= drive to decrease the rate of prediction error[1]**
= drive to increase the amount of learning

1: Pierre-Yves Oudeyer; Frédéric Kaplan, "What is intrinsic motivation? a typology of computational approaches", Frontiers in Neurorobotics 2007

The playground experiment

Shared verbal and motor lexicon acquisition

- **Evolve shared conventionalized symbols to ground visual categories, motor skills, gestures (lexical level), social interaction patterns**

- **First stages of joint action**
- Role of **pointing**
- **Turn taking** & **imitation**
- **Role of emotions**
- **Artificial Curiosity in social context**

- Luc Steels. **Experiments in cultural language evolution**, volume 3. John Benjamins Publishing Company, 2012
- J. Grizou, M. Lopes & P.Y. Oudeyer. **Robot learning simultaneously a task and how to interpret teaching signals**. In IEEE-RAS International Conference on Humanoid Robots, 2012
- L.W. Barsalou. **Grounding symbolic operations in the brain's modal systems**. In Embodied grounding: Social, cognitive, affective, and neuroscientific approaches. Cambridge University Press, 2008
- L. Steels. **Language games for autonomous robots**. Intelligent Systems, IEEE, vol. 16, no. 5, pages 16–22, 2001
- Luc Steels & Manfred. Hild. **Language grounding in robots**. Springer, 2012

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Extending Construction Grammars

- **Beyond lexicon, ground compositional structures like grammar or composite action plans.**

- **Construction Grammars**
- Relationship between **language** and **action**
- Role of **simulation**, in particular in the development of a theory of mind
- Scaffolding **higher-level cognitive** functions.

- Luc Steels. **Design patterns in fluid construction grammar**, volume 11. John Benjamins Publishing Company, 2011
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AI Lab Research Program

Five axis of research

Structuring Perception Layers
-
Patterns extraction

- Deep Learning
- Slow Feature Analysis
- Multi-modal cross-correlation

Categorization For Visual and Motor Schemes
-
Environment modeling, IM

- Proto-object
- Simple motor skills
- Simple causality
- Active Learning
- Intrinsic Motivation

Theory of Mind, Emotions
-
Social modeling

Grounding of language games and social interactions
-
Social Motivation Principle

- Language games => how do they evolve?
- Role of pointing, Theory of Mind
- Turn taking & imitation
- Selectionist approach

Grounding of lexicon and grammar
-
Construction of Meaning

- Construction Grammars
- Relation language & action
- Role of simulation
- Scaffolding higher-level cognitive functions.

Human Cognitive Developmental Map project

- **Gather peer-reviewed known facts about the cognitive and language development of children in a centralized open wiki.**

- Examples:

  Age 12-15 months: *coordinated joint engagement: active triadic interaction, directing other's actions, calling for reengagement if interrupted, taking the other's turn (Bakeman, 1984)*

- Allow for wikipedia style **discussion** and **debates** on “Discussion” page, revision history, list of published **references**, etc.
- **Timescale** representation of selected fact categories based on tags
- **Ranking** of contributors, ranking of fact reliability

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Conclusions

- **Developmental Robotics** as a way to evolve complex representational structures in grounded systems
- **Grounding is key to AI**, to enable simulation-based inferences, creativity and insight
- Key challenges: evolve **categorization** and **joint interactions** between agents
- **AI Lab**: possibility for joint labs, collaborative projects, partnerships, open positions

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Thanks!

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