Agent-Based Modeling in Evolutionary Linguistics

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Guest Lecture: Trends in AI
Brussels, 15 February 2013

"Trend"

This lecture

- **Noun; (I)** A general direction in which something is developing or changing:
  an upwards trend in our company's sales
  (II) A fashion: *the latest trends* (~ *trendy*)
- *Origins:* Germanic, e.g. Old English *trendan* ('to turn in a general direction')
  > Became metaphor in 19th Century
  > Spatial sense disappeared

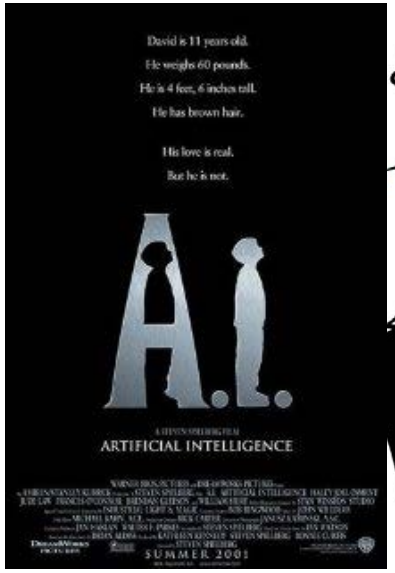
Trends in AI

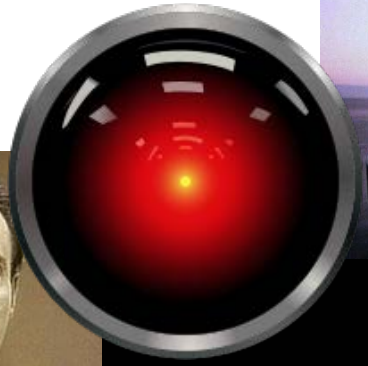
- "Automaton"
  > Greek origins, 'acting of one's own will'
  > autonomous systems
- "Andr-oid"
  > Greek origins, 'like a (hu)man'
- "Robot"
  > Introduced by Chzech writer Karel Čapek in a theater play in 1920
  > stems from *robota* ('serf labor', 'corvée')

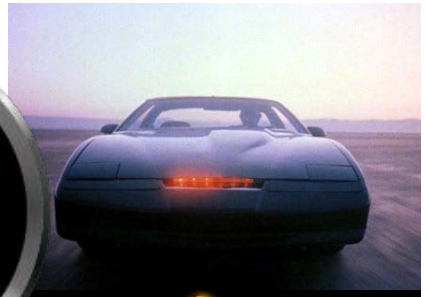
Autonomous Agents

- 250 BC: Chinese *Lie Zi* book describes human-like automaton
- 50 BC: Greek mathematician *Hero of Alexandria* invents vending machines, machines for pouring wine, ...
- 13th Century: *Al-Jazari* invents a musical robot band, drink-serving waitress, ...
- ...

Autonomous Agents



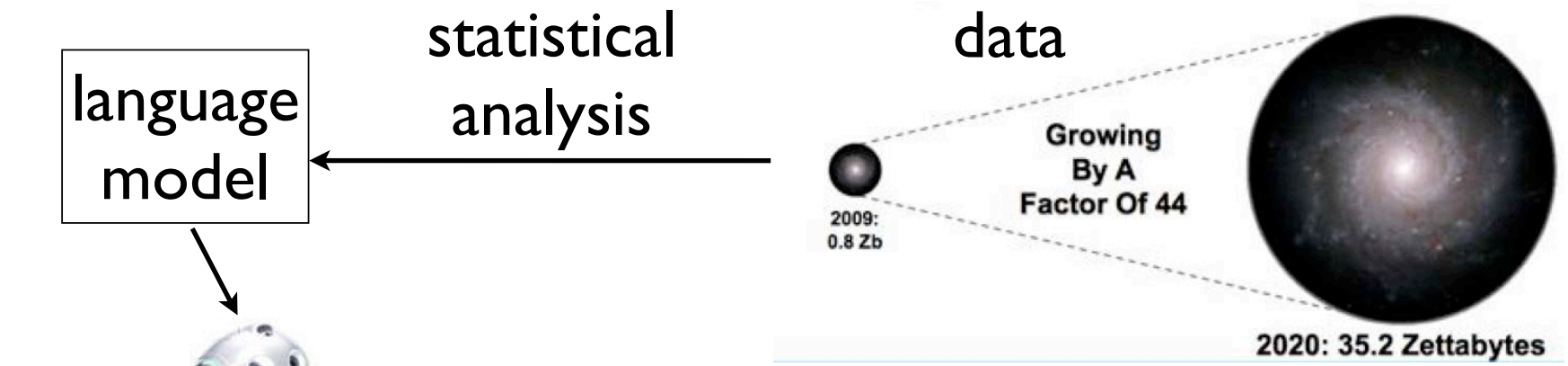




Hypothesis

- **Language** is a key ingredient to bootstrap the intelligence of autonomous agents to human-like cognition
- We must understand how language...
  > is processed and learned
  > emerges and evolves

How can agents learn to use language?



But does this approach work??

Dominant approach to language processing

Dominant approach: probabilistic

Mostly solved:

- Spam detection — *buy V I aGrA...*
- Parts-of-speech tagging — *[the$_{noun}$][idea$_{noun}$]*
- Named entity recognition — *Einstein met the UN officials.*

Progress being made:

- Sentiment analysis — *The waiter ignored us for 20 minutes.*
- Word sense disambiguation — *I need a new mouse for my pc.*
- Information extraction — *You're invited to our party on Friday, March 23.*

Dominant approach: probabilistic

Still problematic:

- Question-answering

How effective is ibuprofen in reducing fever in patients with acute febrile illness?

- Summarization and paraphrasing
- Dialog

Really, really hard

- Human-machine interaction
- Linguistic creativity

Some Observations in Language

Crazy English

- Your nose can run and your feet can smell.
- Most bathrooms do not have a bath.
- Apartments are actually together.
- Women can man a station, but men can't women one
- A writer writes and a singer sings. But fingers don't fing, hammers don't ham and grocers don't groce

Crazy English

- Old news
- Awfully good
- A small fortune
- Loose tights
- Open secret
- Recorded live
- act naturally
- Microsoft Works

Crazy English

- Fatal attack leaves no survivors
- I'm going to proceed ahead
- 100 percent pure
- A new innovation
- He had no peers or equals
- Talk about your past experiences
- At this point in time

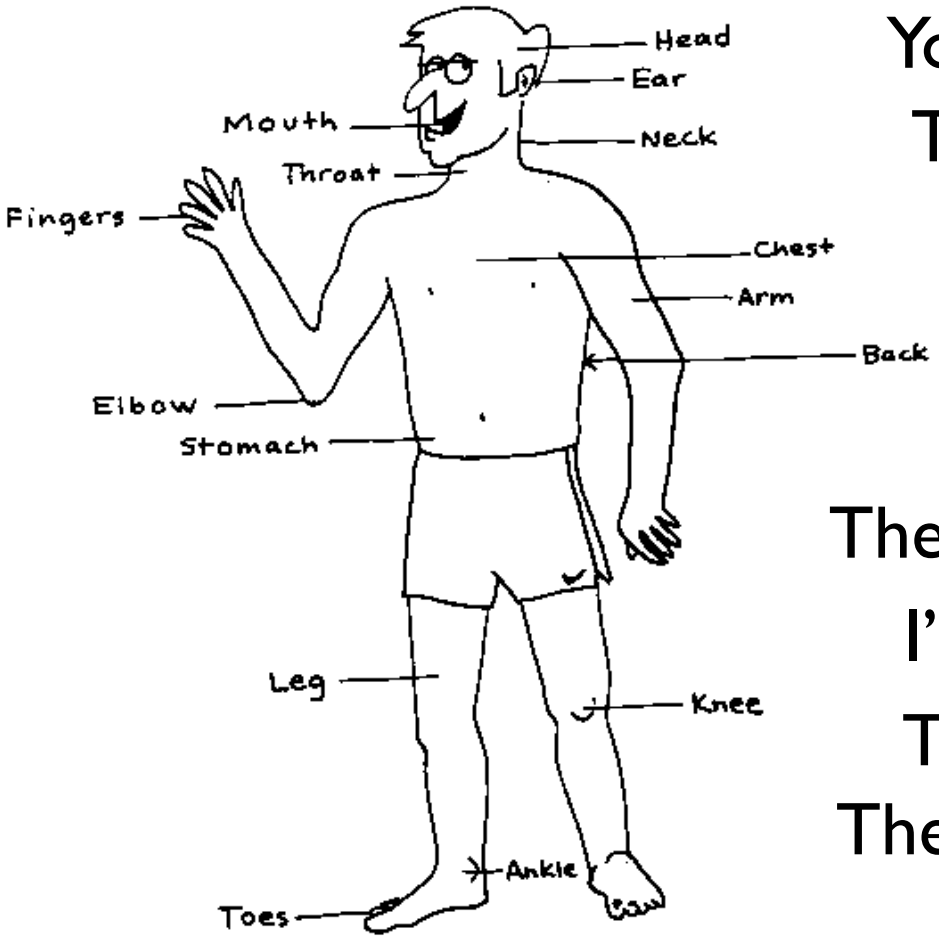
Crazy Dutch/Flemish

- Hij zit in de kelder.
  He is in the basement.
  (lit.: *he sits in the basement*)
- Hij kwam op mij af gelopen.
  He came up to me.
  (lit.: He came up me down running)
- Ze is volslank.
  She's a bit chubby.
  (lit.: she is full-skinny)

Crazy French

- Est-ce que c'est vrai qu'elle est française?
  Is it true that she's French?
  (lit: *Is it that it is true that she is French?)*
- Au jour d'aujourd'hui.
  The day today.
  (lit.: *At the day of at the day of today).*
- C'est terrible!
  That's great!
  (lit.: it is terrible)

Language is embodied



You find it at the **back**.

The building **faces** south.

Face your demons.

It is **behind** you.

It is in **front** of you.

The **heart** of the problem.

I'm **knee**-deep in trouble.

The **eye** of the storm.

The **head** of the company.

I have a **gut** feeling.

Language is embodied

- Artificial
  > from Latin *artificium* ('made by man')
  > *ars* ('art/craft') + *facere* ('do')
  > *ars* is related to *arm*

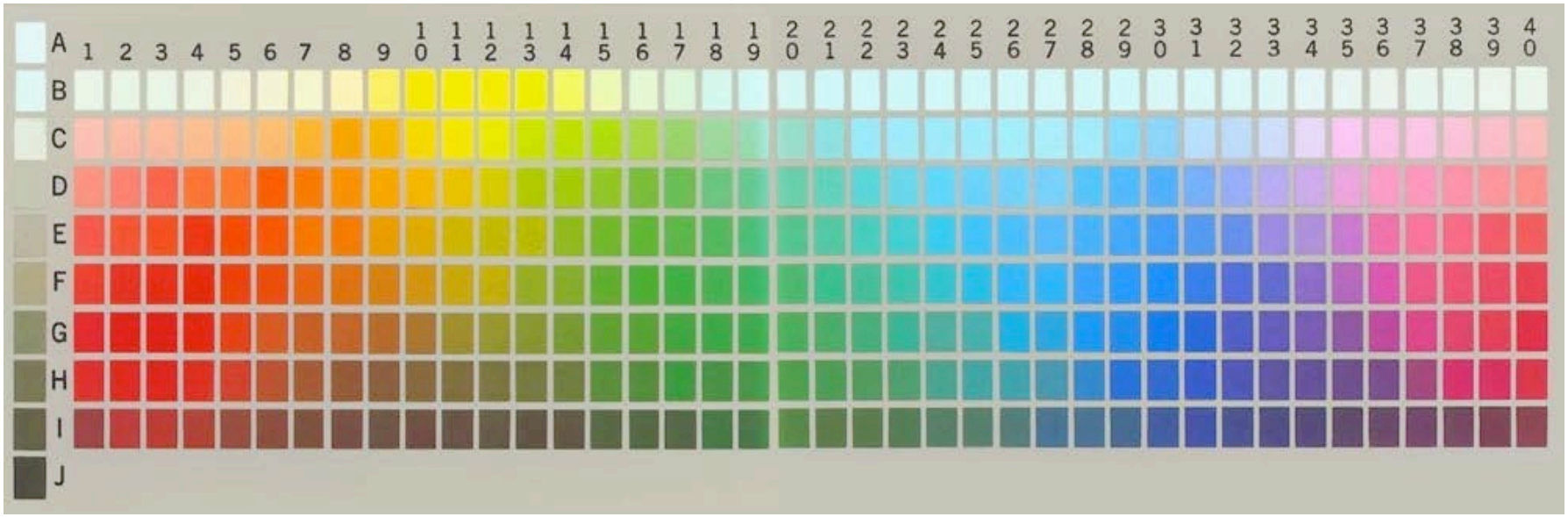
- Intelligence
  ~ Latin *intelligere* ('to understand')
  ~ *inter-* ('between') + *legere* ('choose/pick')
  (related to *lecture*)

- Guest lecture
  = things selected by a stranger

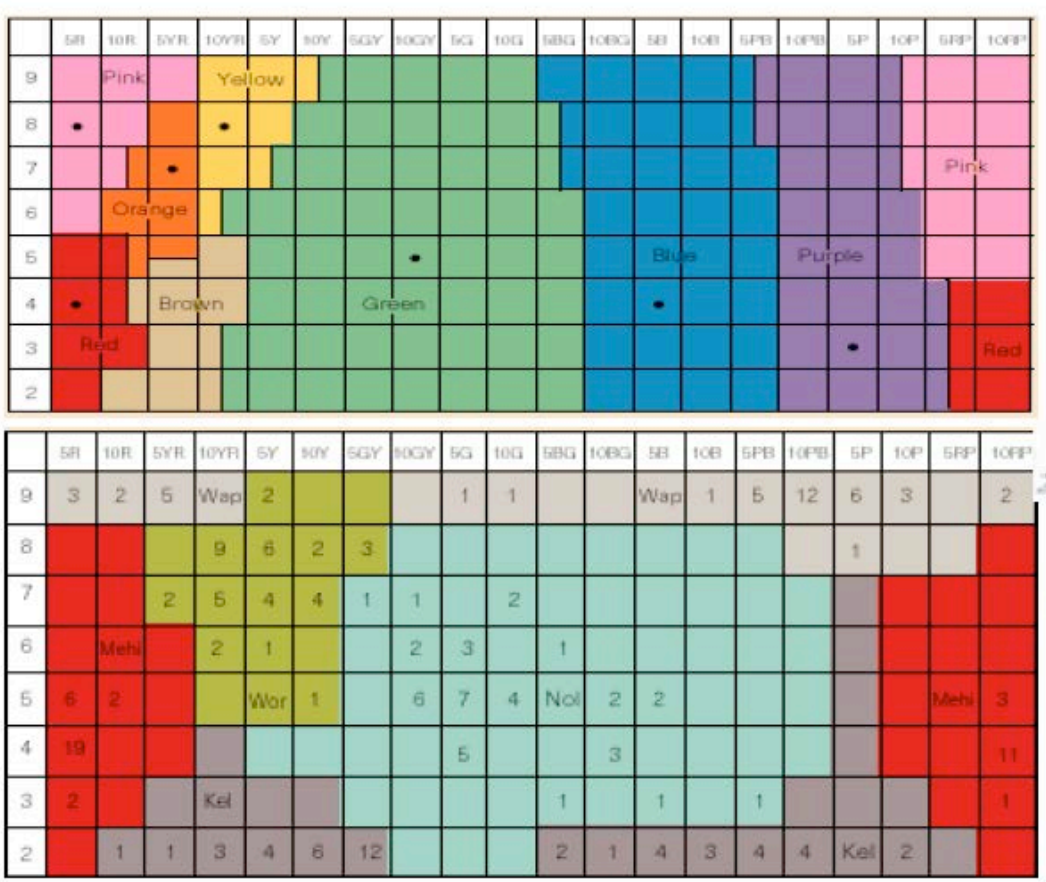
Language is cultural

- English: *The cat is in front of the tree.*
- Hausa: *The cat is behind the tree.*
- Tonga: *The cat is at the seaside of the tree.*

Language is cultural



Language is cultural



English

Berinmo

(Davidoff, Roberson, et.al. *Nature*, 1999)

Language is cultural

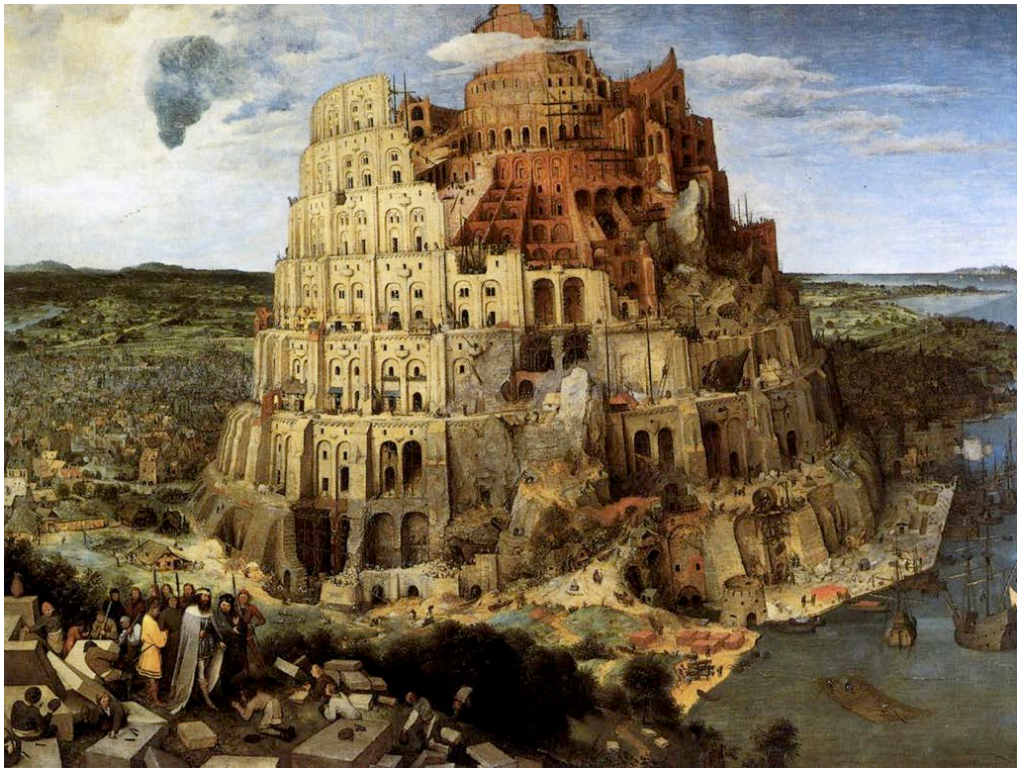
"Now! *That* should clear up a few things around here!"

Evolutionary Linguistics

Luc Steels, ed. (2012). *Experiments in Cultural Language Evolution*, Amsterdam: John Benjamins.

Origins and evolution of language

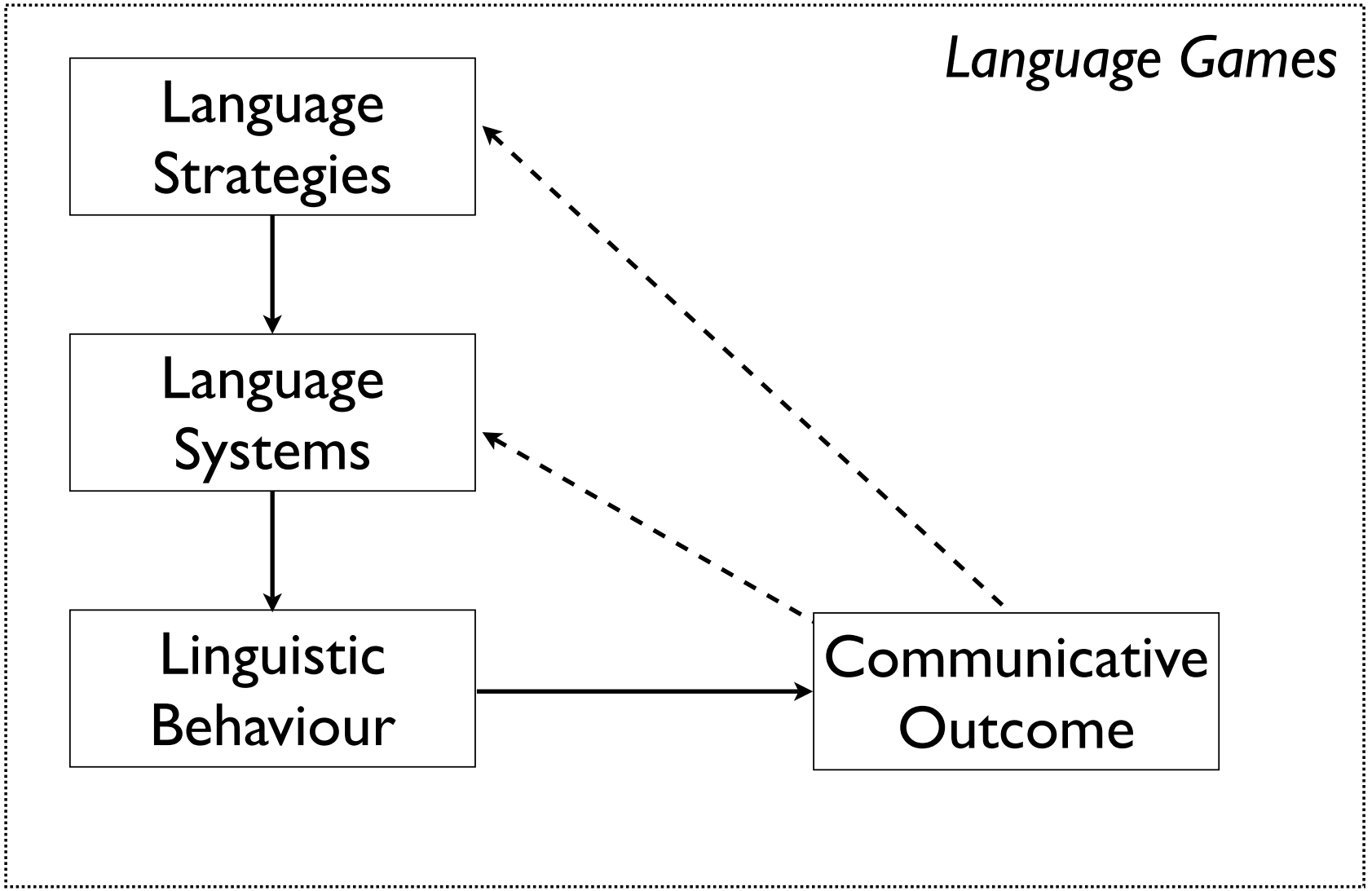
The Fall of Adam, 1470
Hugo Van der Goes



Tower of Babel, 1563
Pieter Breughel The Elder

Cultural Linguistic Selection

- Variation
- Testing variants against selection criteria
  - Communicative success
  - Cognitive effort
  - Expressivity
  - Social conformity
  - ...



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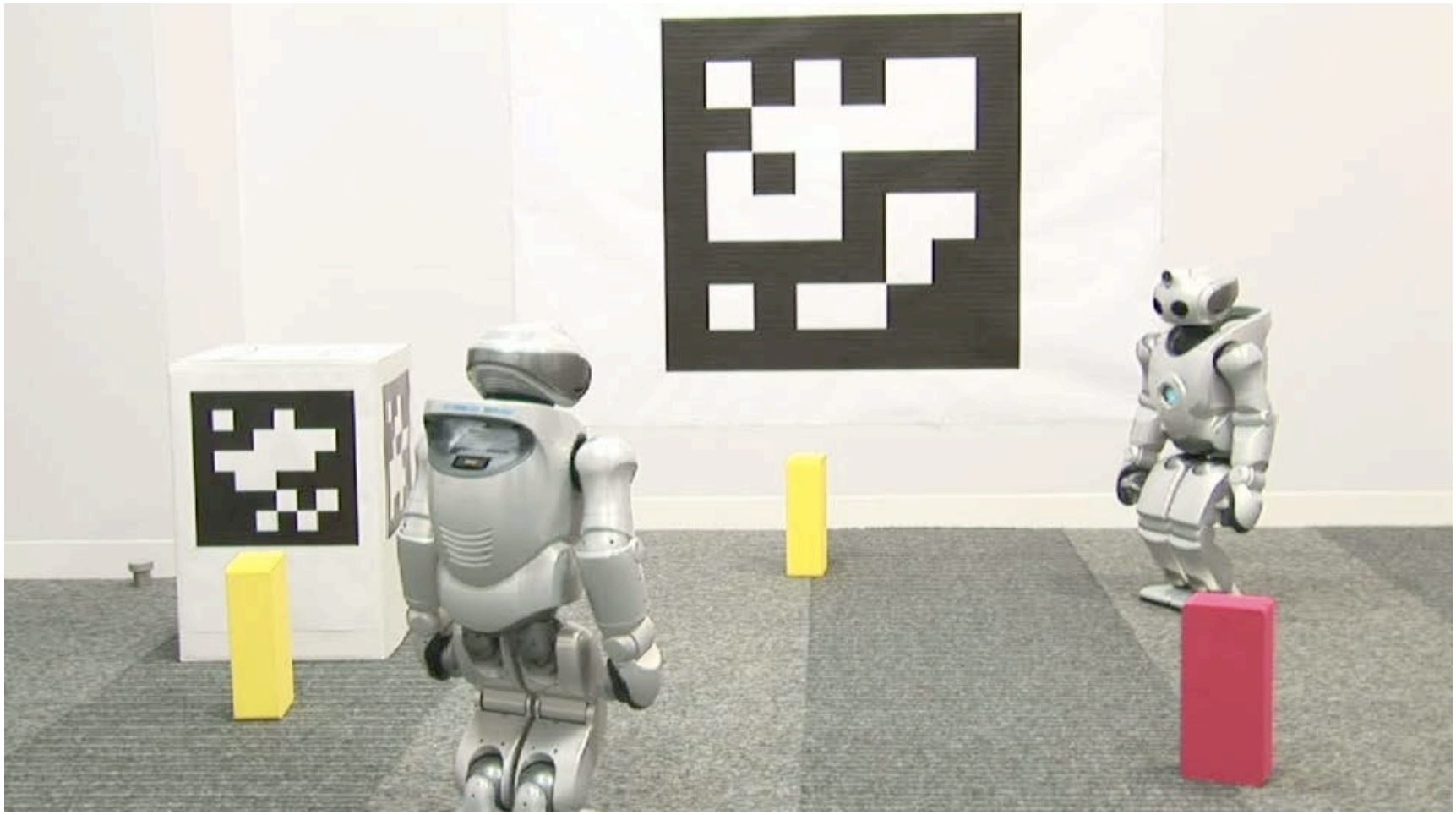
Language Games

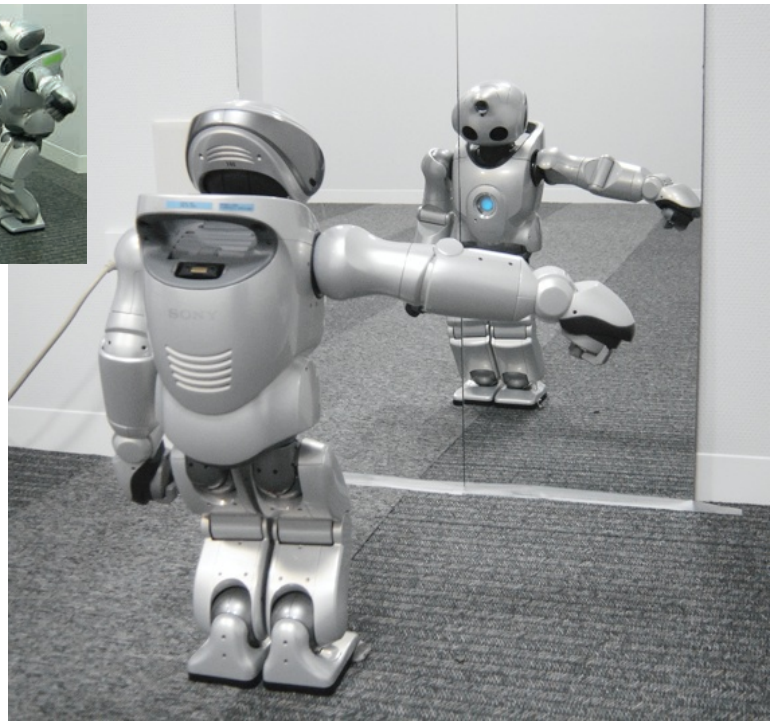
Language games

- **Routinized interactions** between two or more agents in a **locally situated** environment
- Integrate the various activities required for dialogue
- Provide a communicative context



Let agents play language games

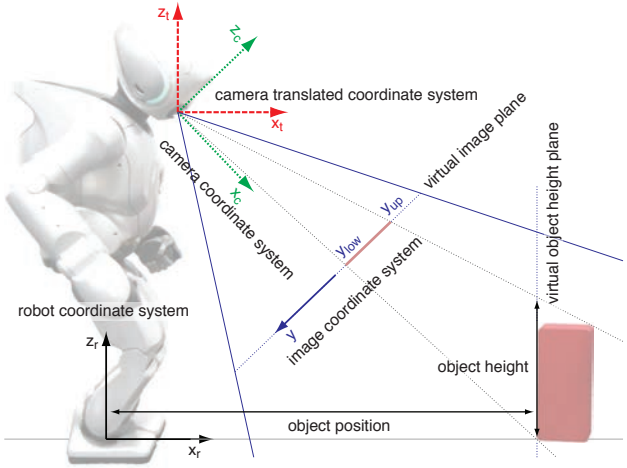
Sony Qrio



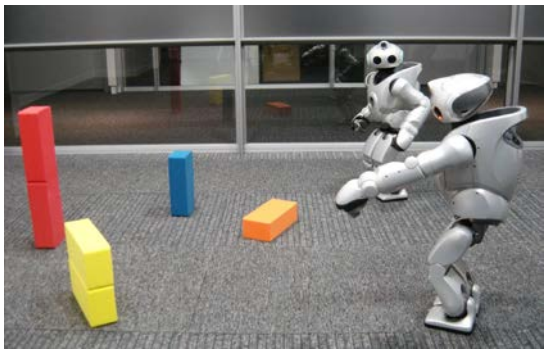
Myon
(Humboldt U.
Berlin)

A “Whole Systems” Approach

Embodiment and vision



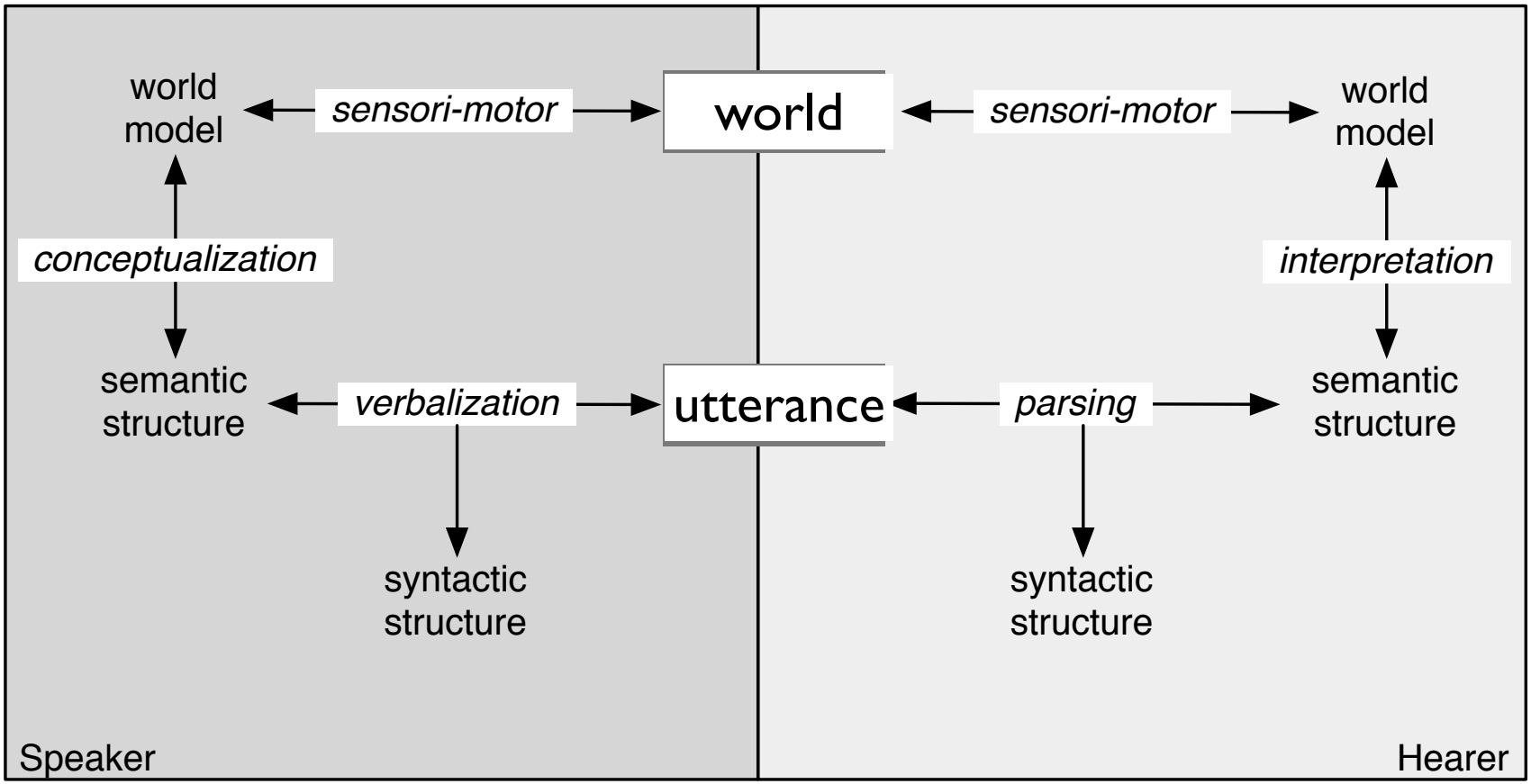
Interaction with the real world



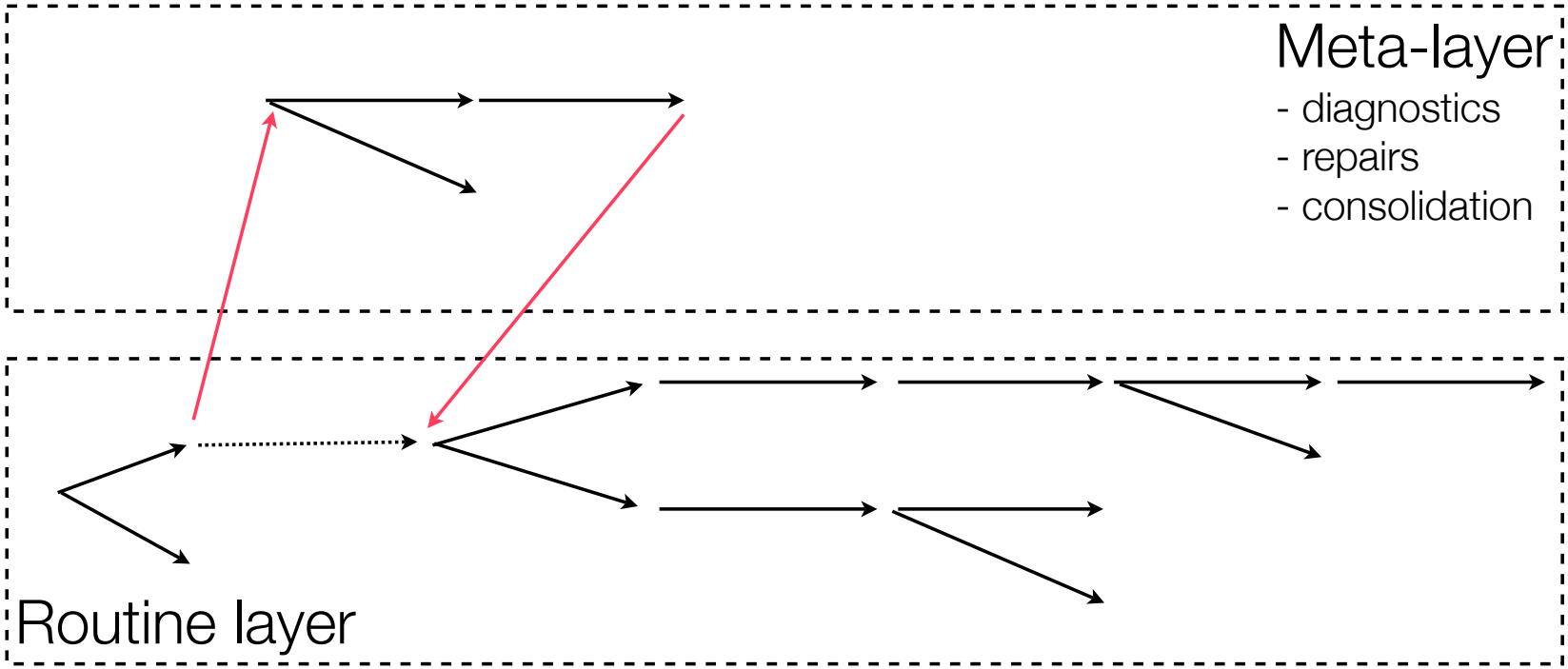
Conceptualization

Language

Semiotic Cycle



Problem-solving: two-level processing system



Language technologies

Babel2

- Sensori-motor processing
- Rich semantics IRL
- Fluid grammars FCG

www.fcg-net.org

Sensori-motor processing

- **Grounding**
  Connecting representations to reality through the robot's sensori-motor apparatus
- **Embodiment**

Open-ended: new situations, noisy perception, ...

Rich semantics

- **Conceptualization**
  Planning what to say.
- **Interpretation**
  Plan "execution"
  ("apply" the meaning to the real world)

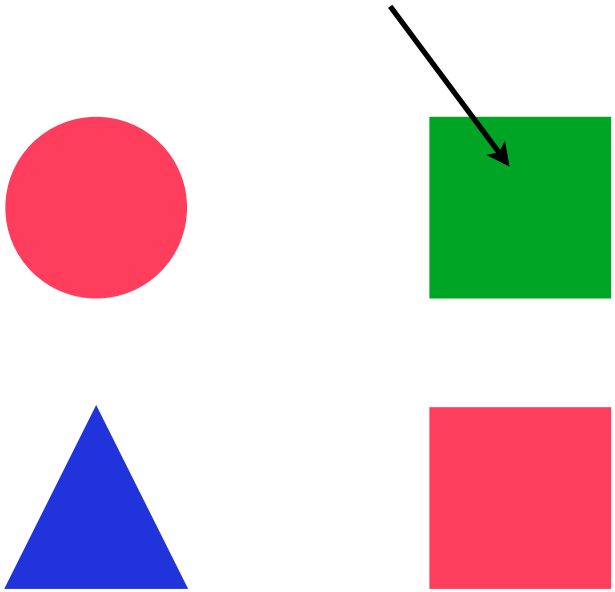
Open-ended: new meanings, categories, ...

Incremental Recruitment Language (IRL)

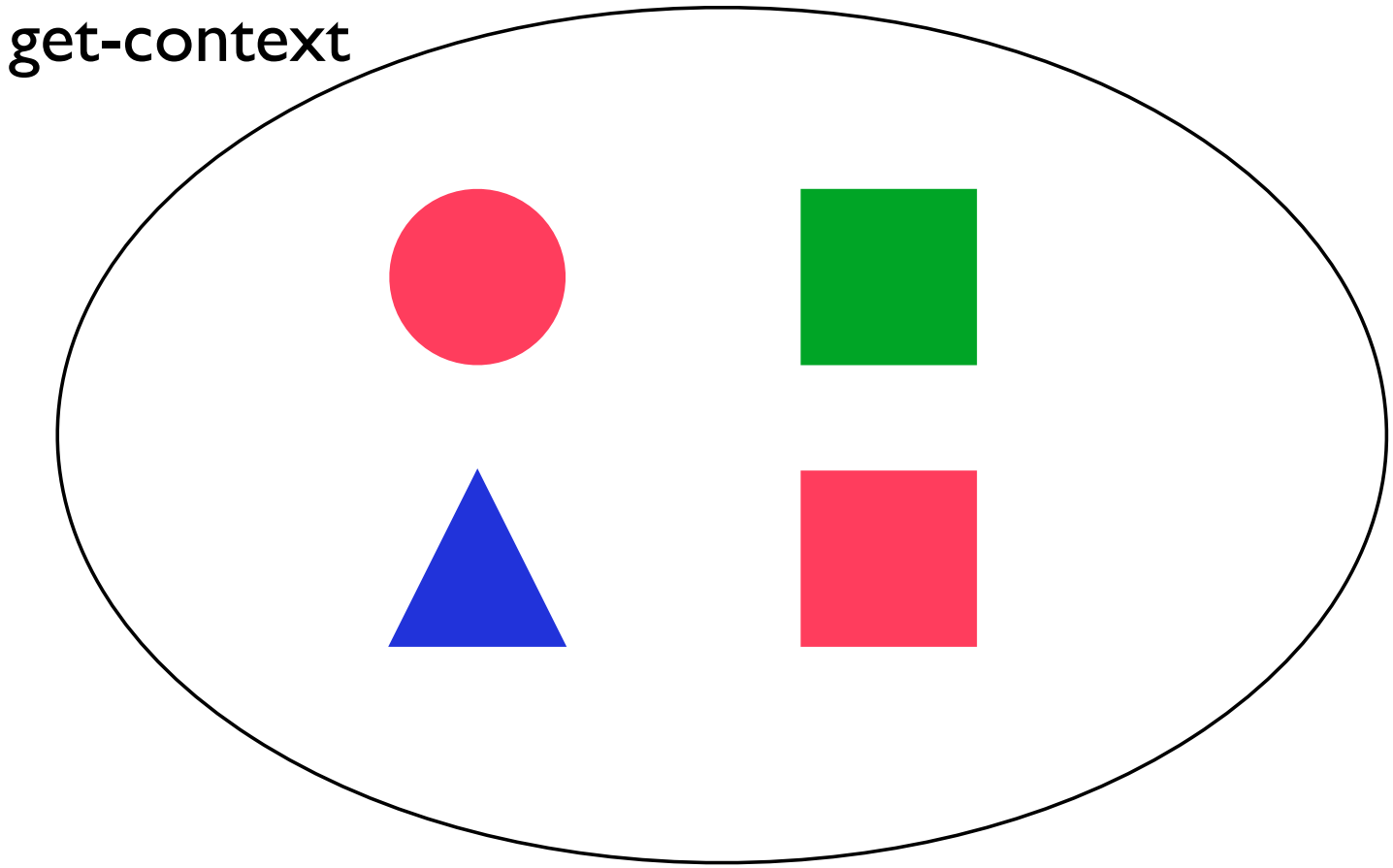
- Speaker uses language to achieve a communicative effect in the hearer's mind
- Procedural semantics: meaning is like a semantic program that the speaker wants the hearer to execute

Referential game

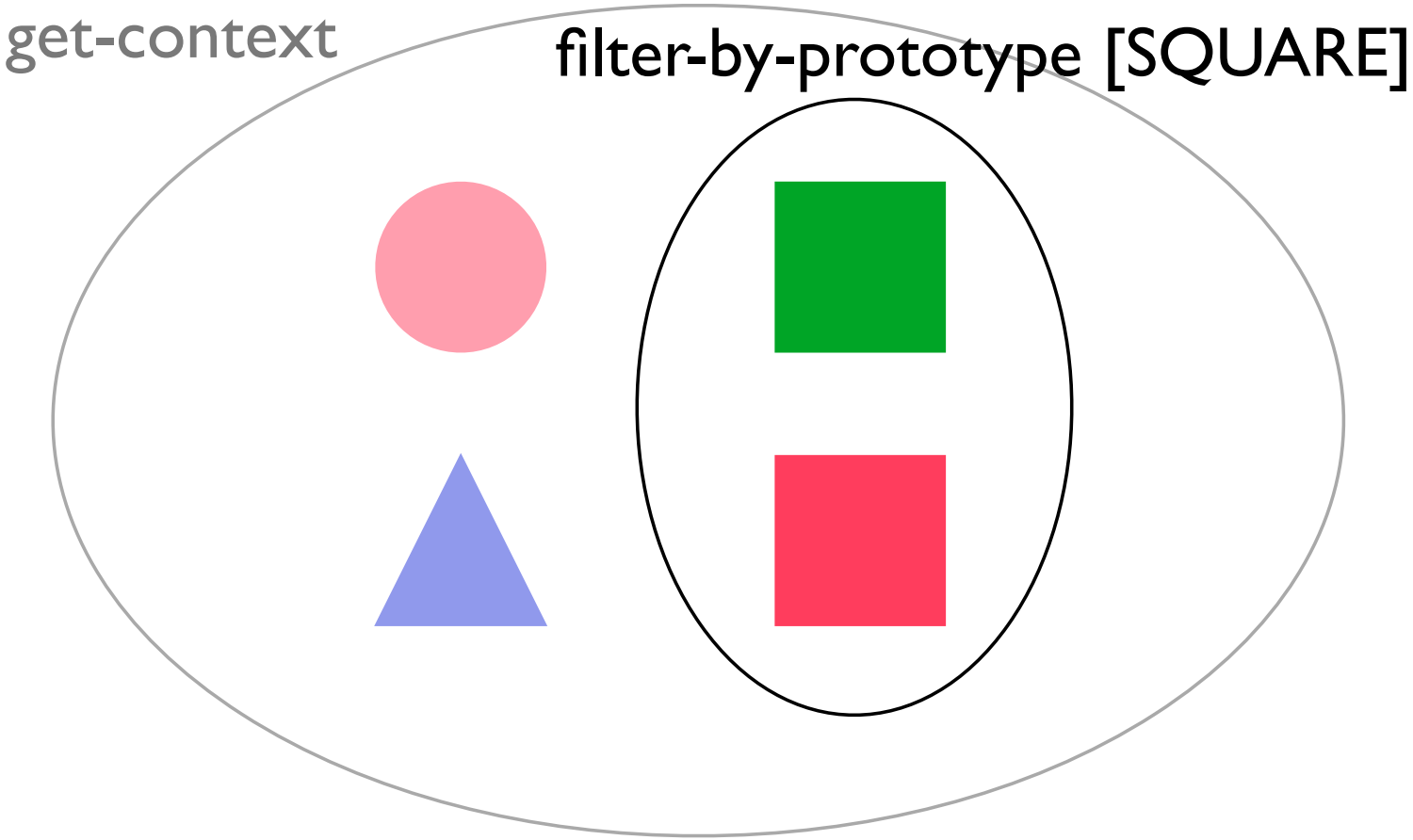
The speaker wishes to draw the hearer's attention to this object using language



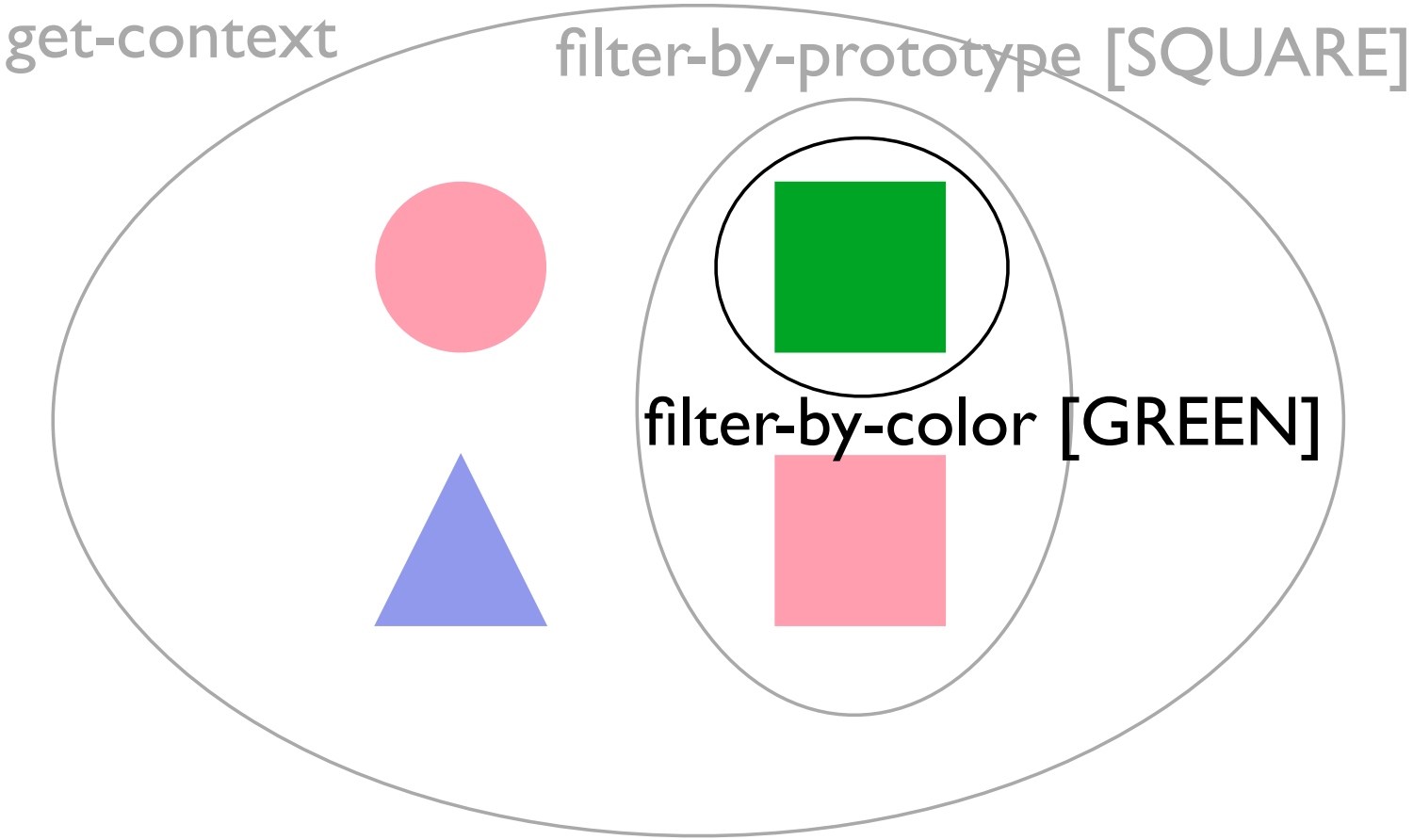
Referential game



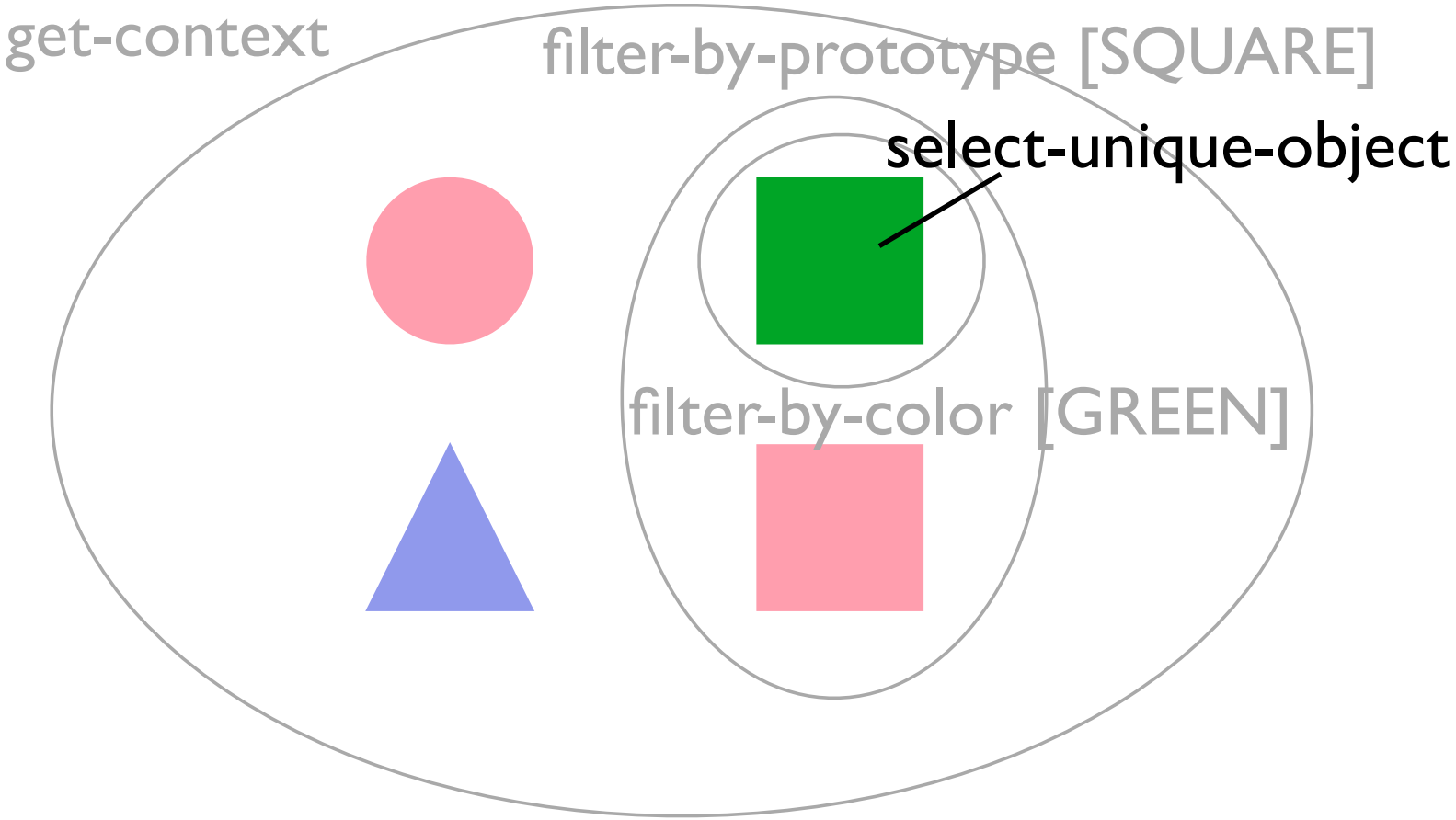
Referential game



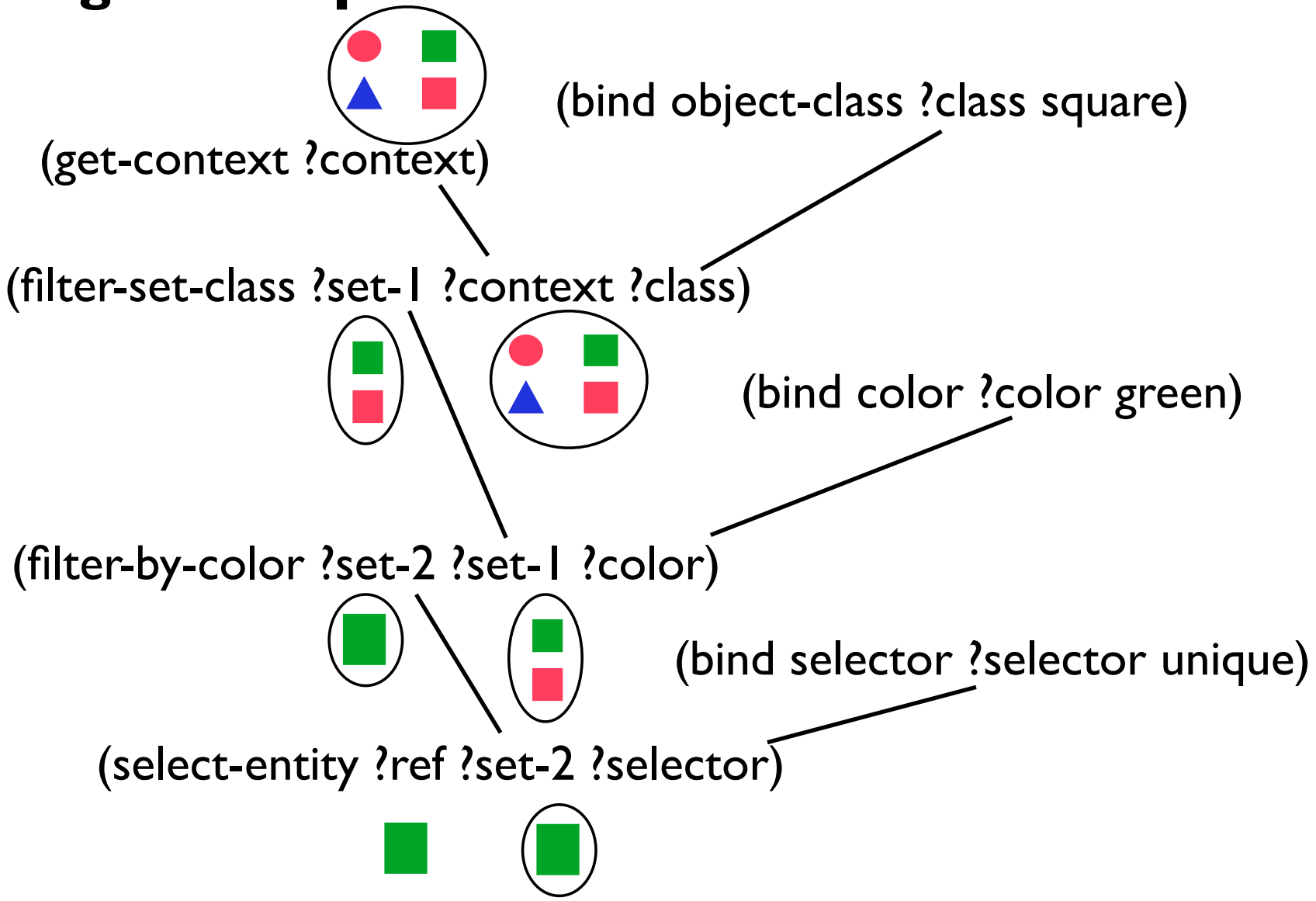
Referential game



Referential game



IRL networks:
cognitive operations + bind statements



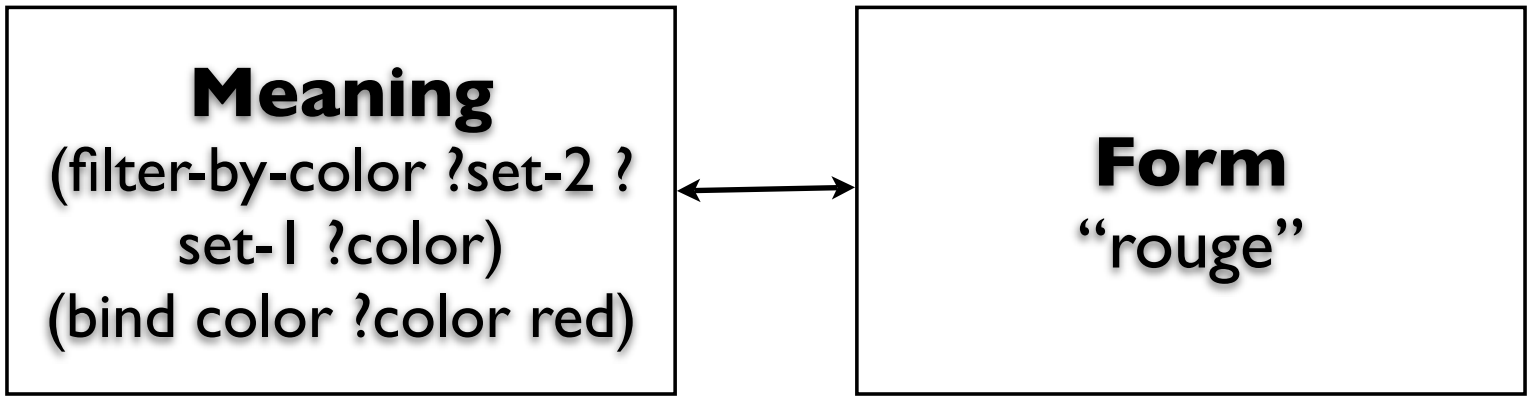
Fluid grammars

- **Production**
  Verbalizing a meaning into an utterance
- **Parsing**
  Parsing an utterance into a meaning

Open-ended: new words, grammatical constructions, personal preferences, ...

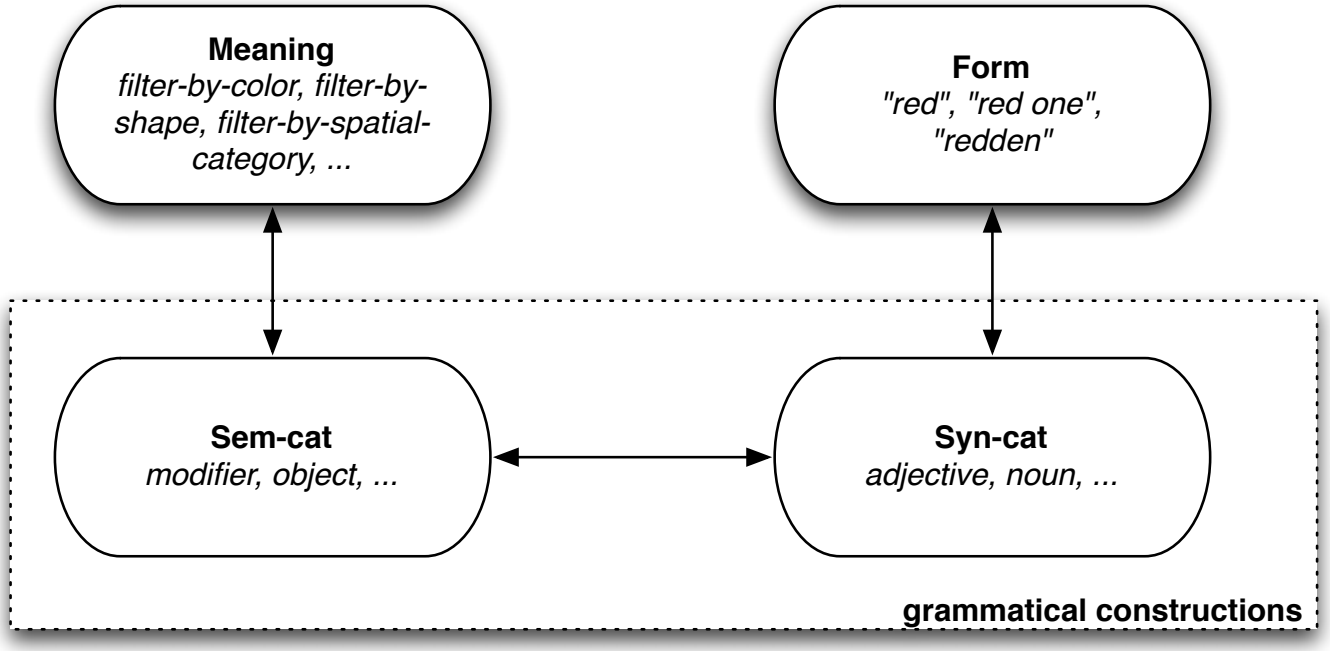
Fluid Construction Grammar (FCG)

- Grammar expresses conceptualizations through meaning-form mappings
- Construction grammar



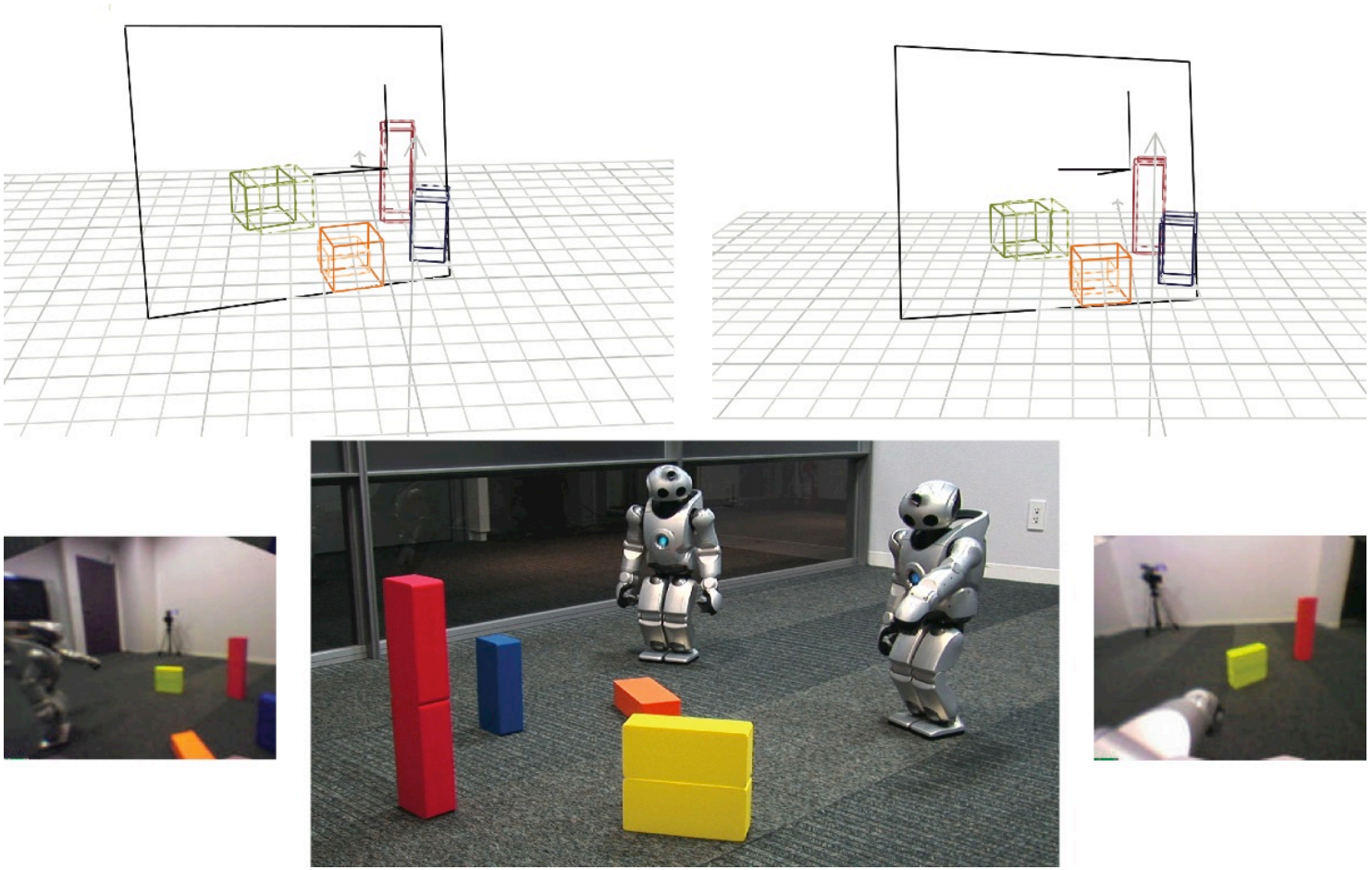
Fluid Construction Grammar (FCG)

- Intermediary layer of semantic and syntactic categories

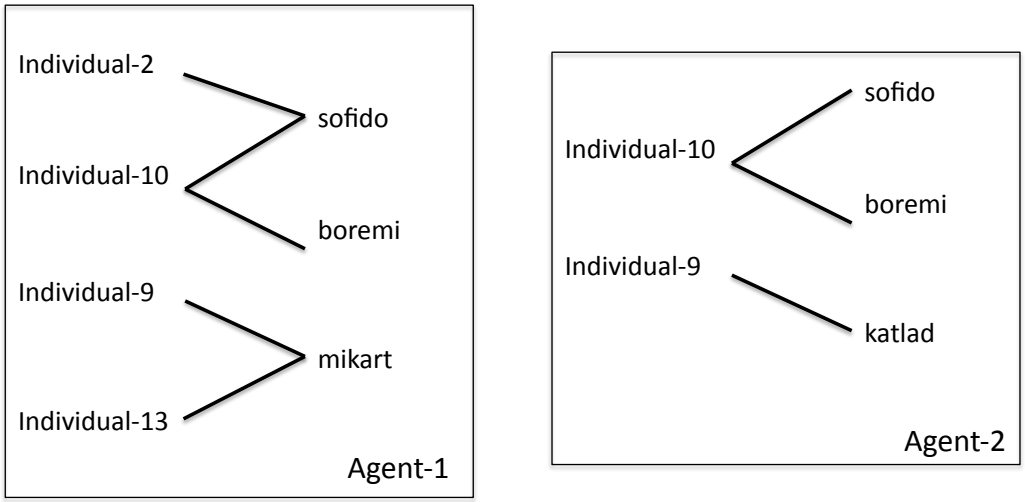


Example 1
The Naming Game

- Steels, Luc (1995). "A Self-Organizing Spatial Vocabulary."
- Steels, Luc and Loetzsch, Martin (2012). "The Grounded Naming Game."
- Wellens, Pieter (2012). *Adaptive Strategies in the Emergence of Lexical Systems*.



Luc Steels and Martin Loetzsch (2012). The Grounded Naming Game. In: Luc Steels (ed), *Experiments in Cultural Language Evolution*, Amsterdam: John Benjamins.



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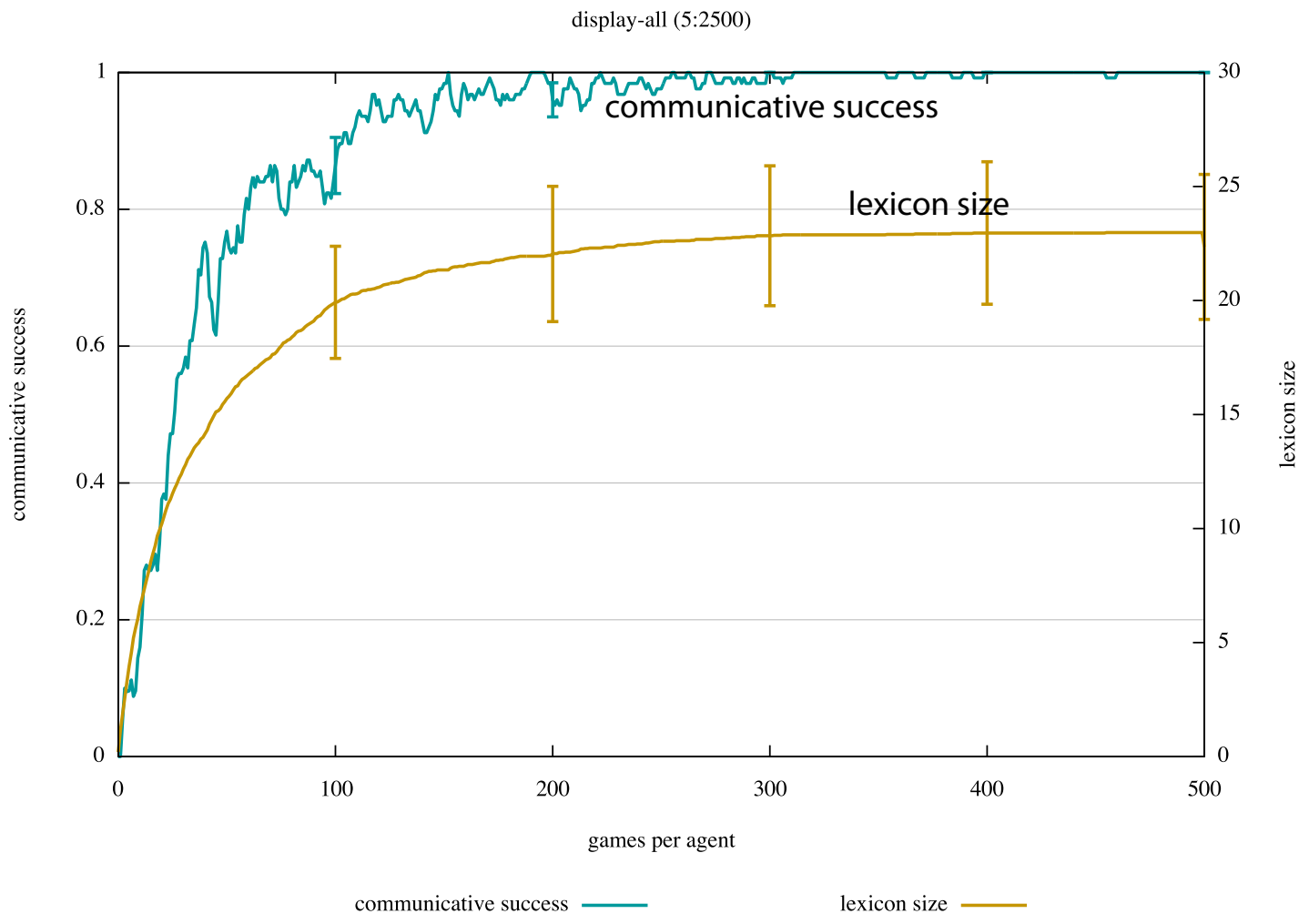

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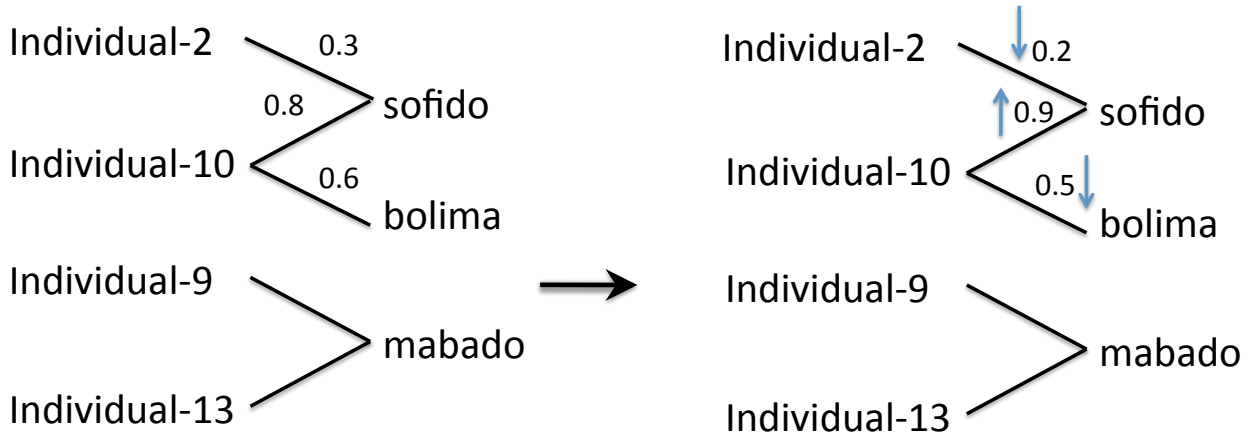
Power of Self-Organization

Termite Mound
(Cape York, Australia)

Sagrada Familia
(Barcelona)



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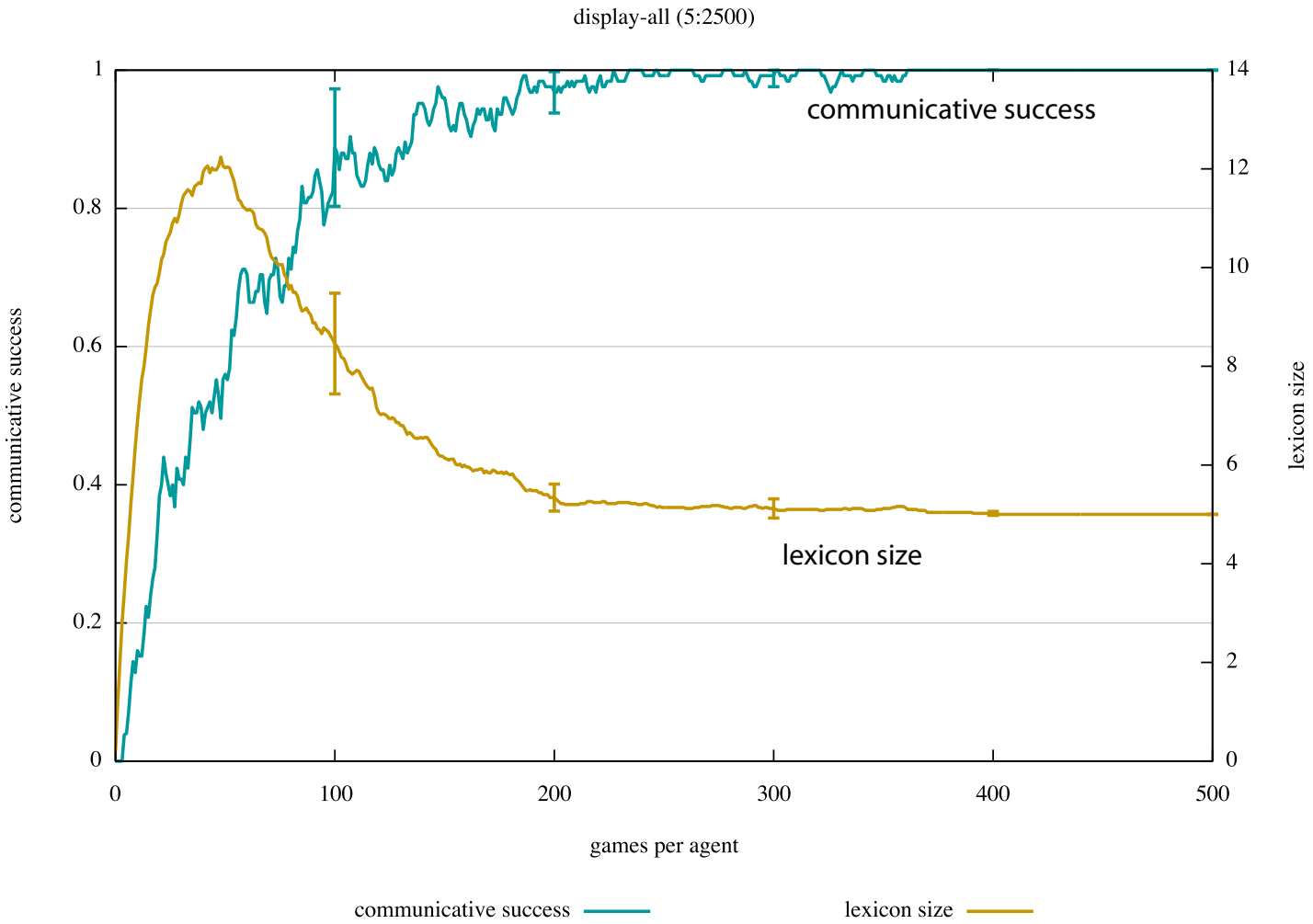

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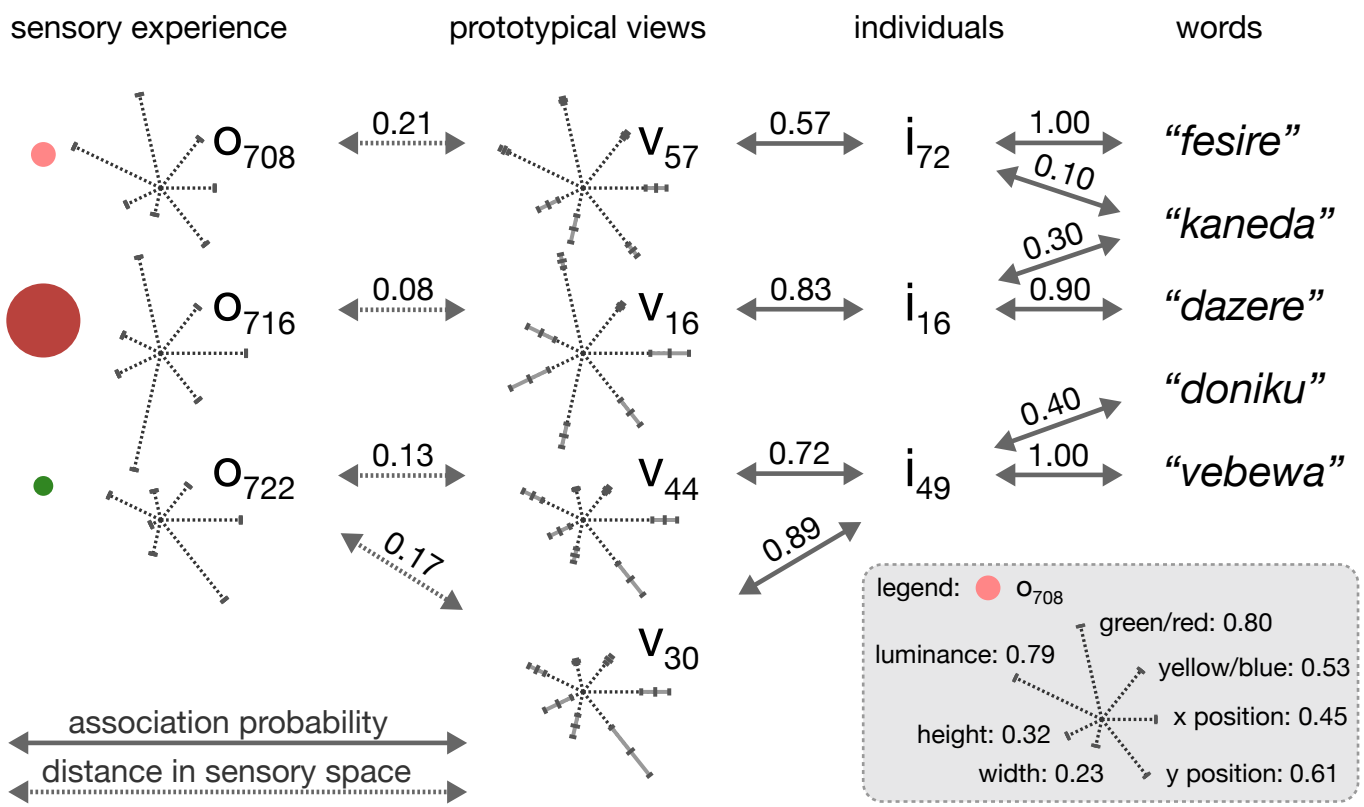
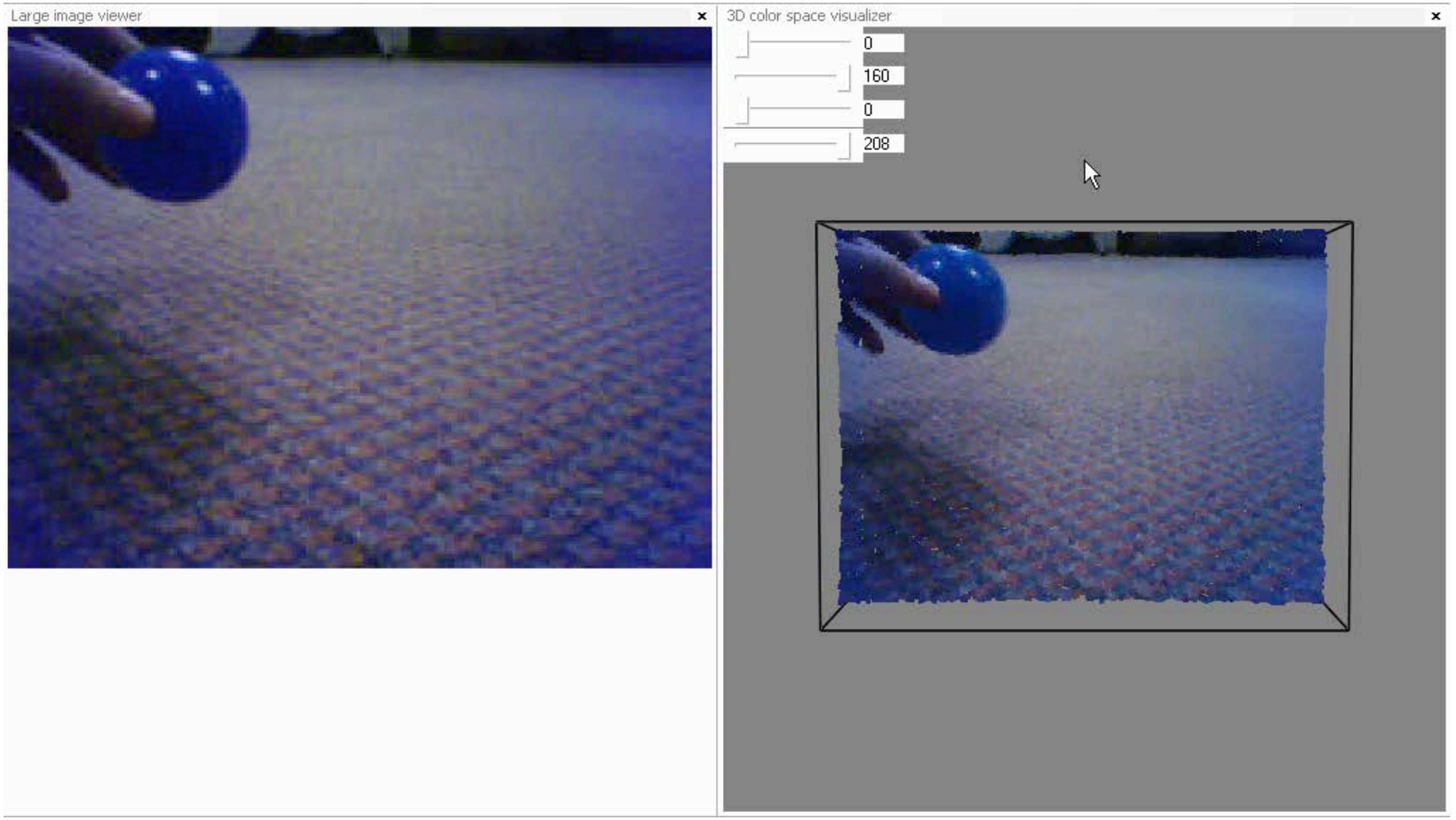


Luc Steels and Martin Loetzsch (2012). The Grounded Naming Game. In: Luc Steels (ed), *Experiments in Cultural Language Evolution*, Amsterdam: John Benjamins.

Example 11
The Color Game

- Steels, Luc and Tony Belpaeme (2005). "Coordinating Perceptually Grounded Categories Through Language: A Case Study For Colour."
- Bleys, Joris (2012). "Language Strategies for Color."

Detecting Color



Example III
The Emergence of Grammar

- van Trijp, Remi (2012). "The Evolution of Case Systems for Marking Event Structure."
- van Trijp, Remi (2012). "Self-Assessing Agents for Explaining Language Change."

Model

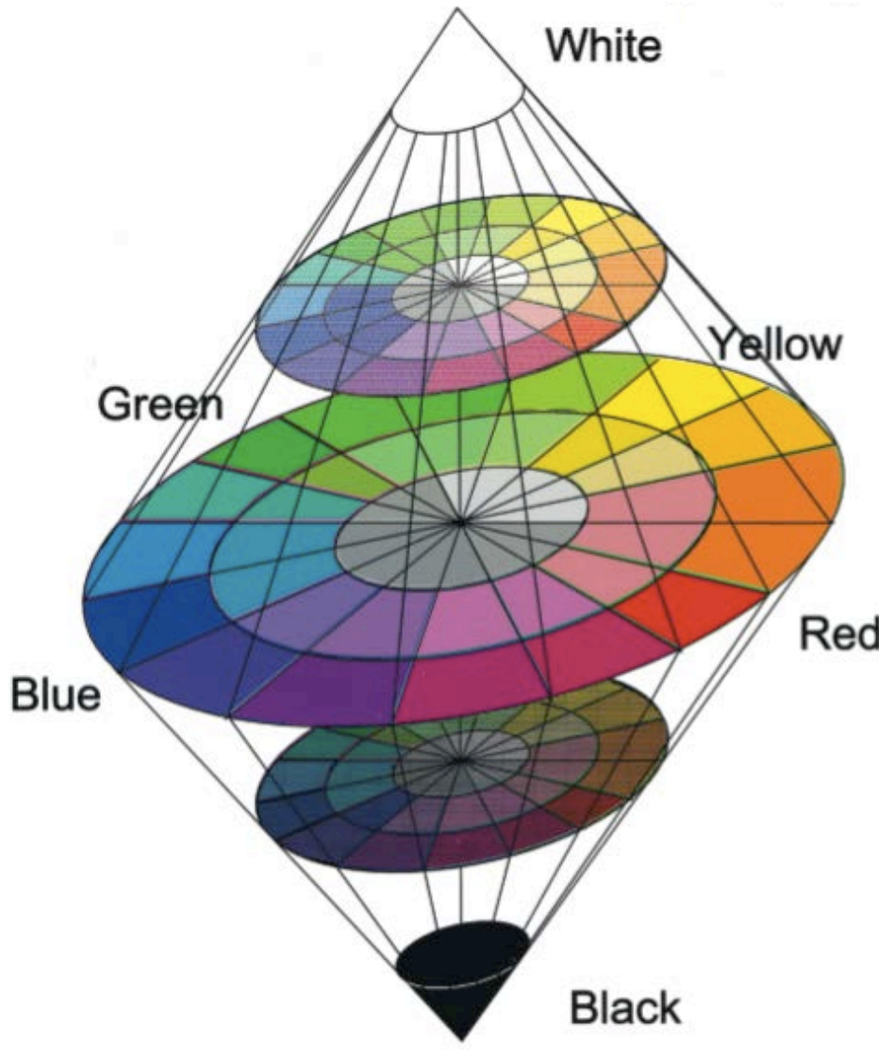
- design language game in which colour is functionally relevant

- each use of a colour category is operationalised as a different language strategy

  - full colour space: all dimensions of the colour space are used

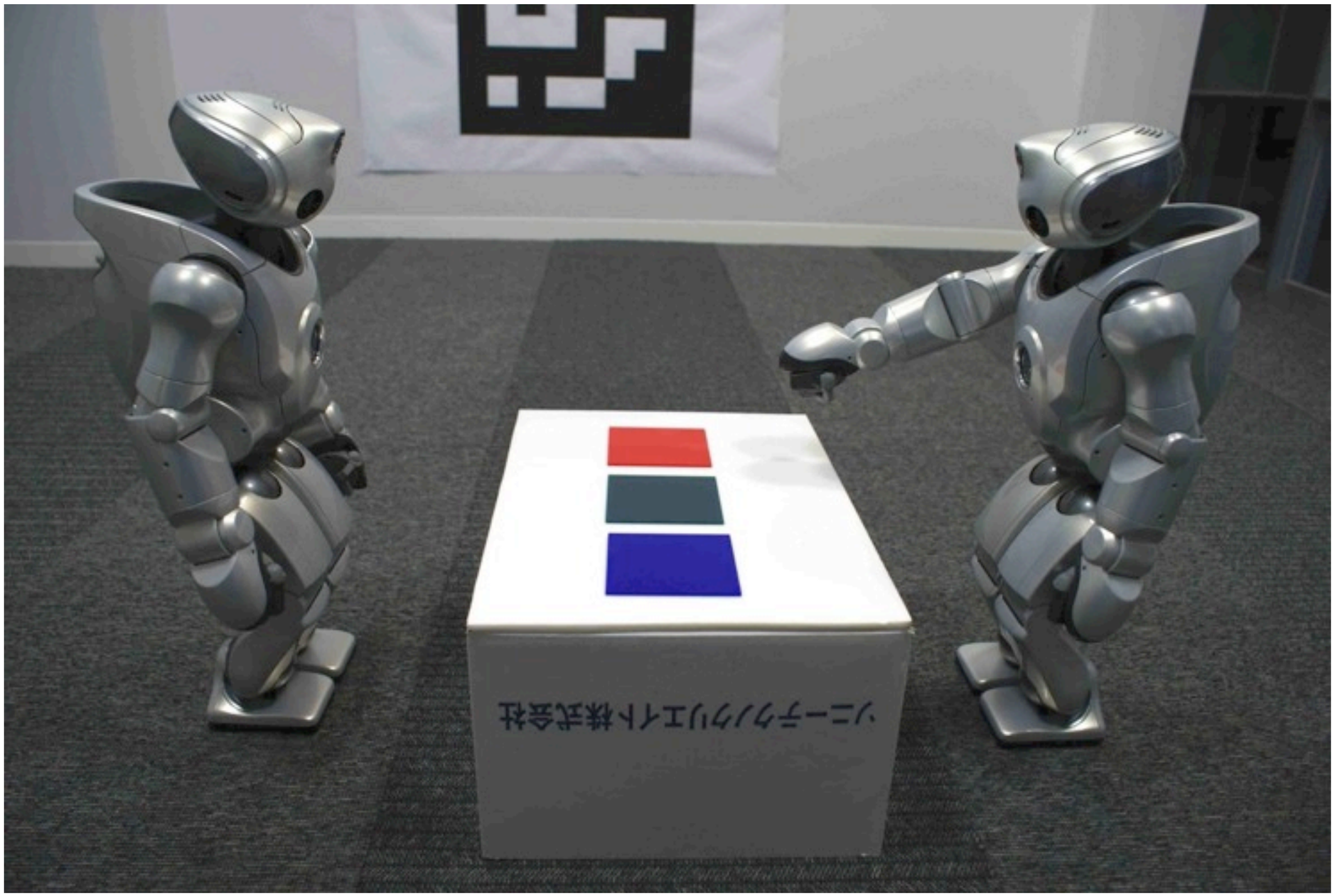
  - brightness: only brightness (*L**) dimension of colour space is used

- add layer of linguistic selection of language strategies



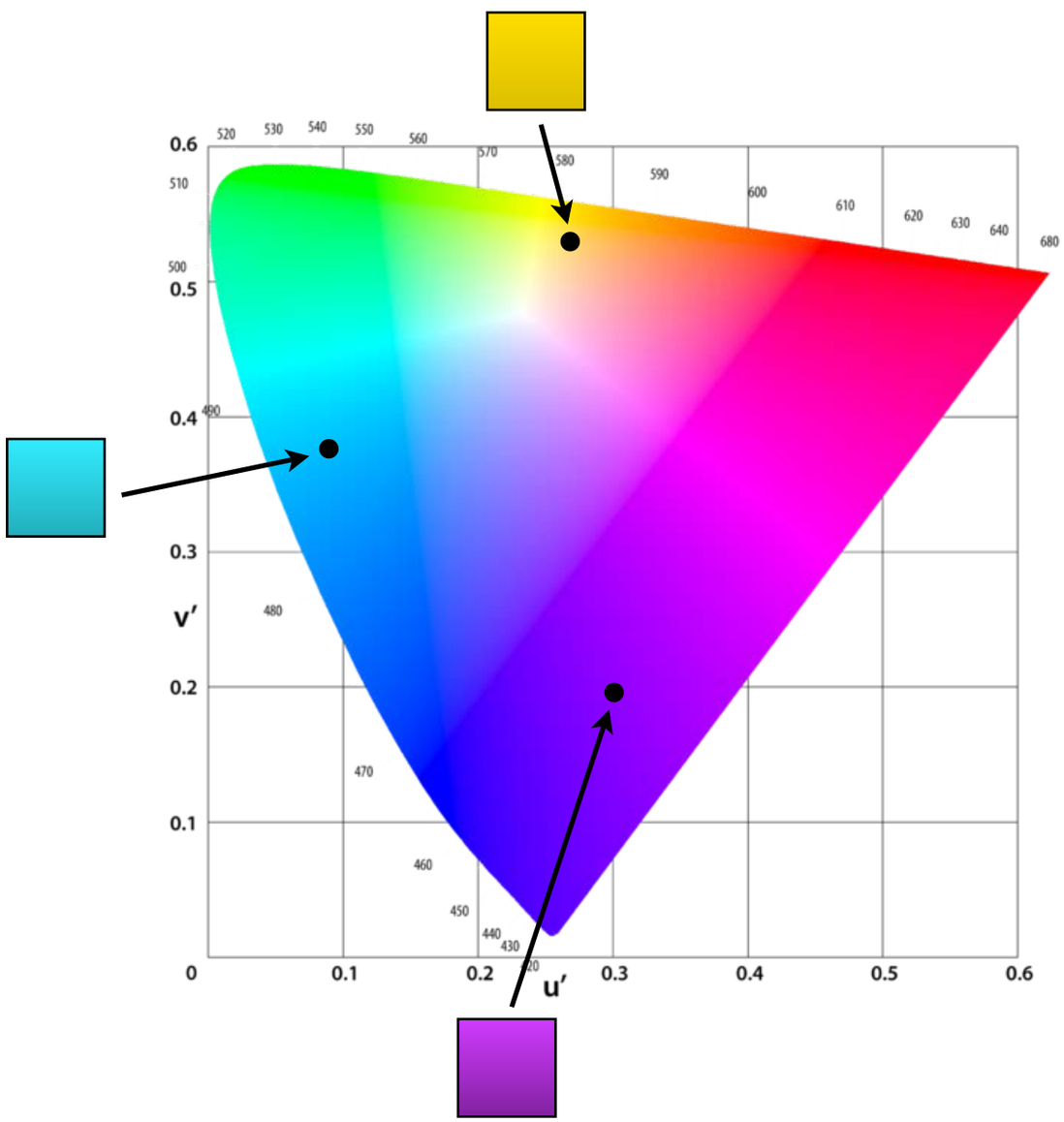
Bleys, J. and Steels, L. (2009) Linguistic Selection of Language Strategies: A Case Study for Colour. Proceedings of ECAL09.

Colour Naming Game



Steels, L. and Belpaeme, T. (2005) Coordinating perceptually grounded categories through language: a case study for colour. Behavioral and Brain Sciences **28**(4), 469–489

Full Colour Space Strategy: production & interpretation



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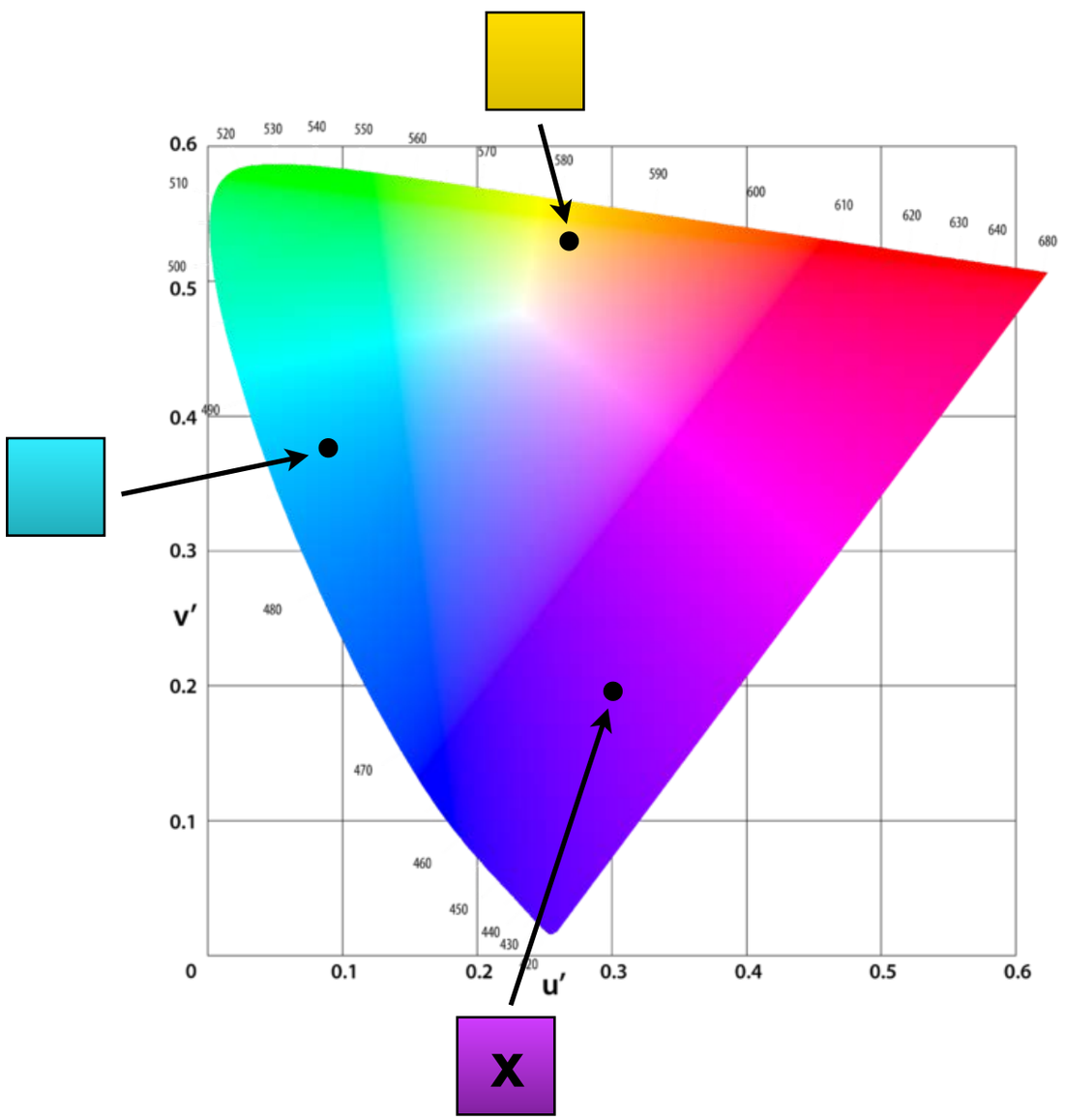
Full Colour Space Strategy: production & interpretation



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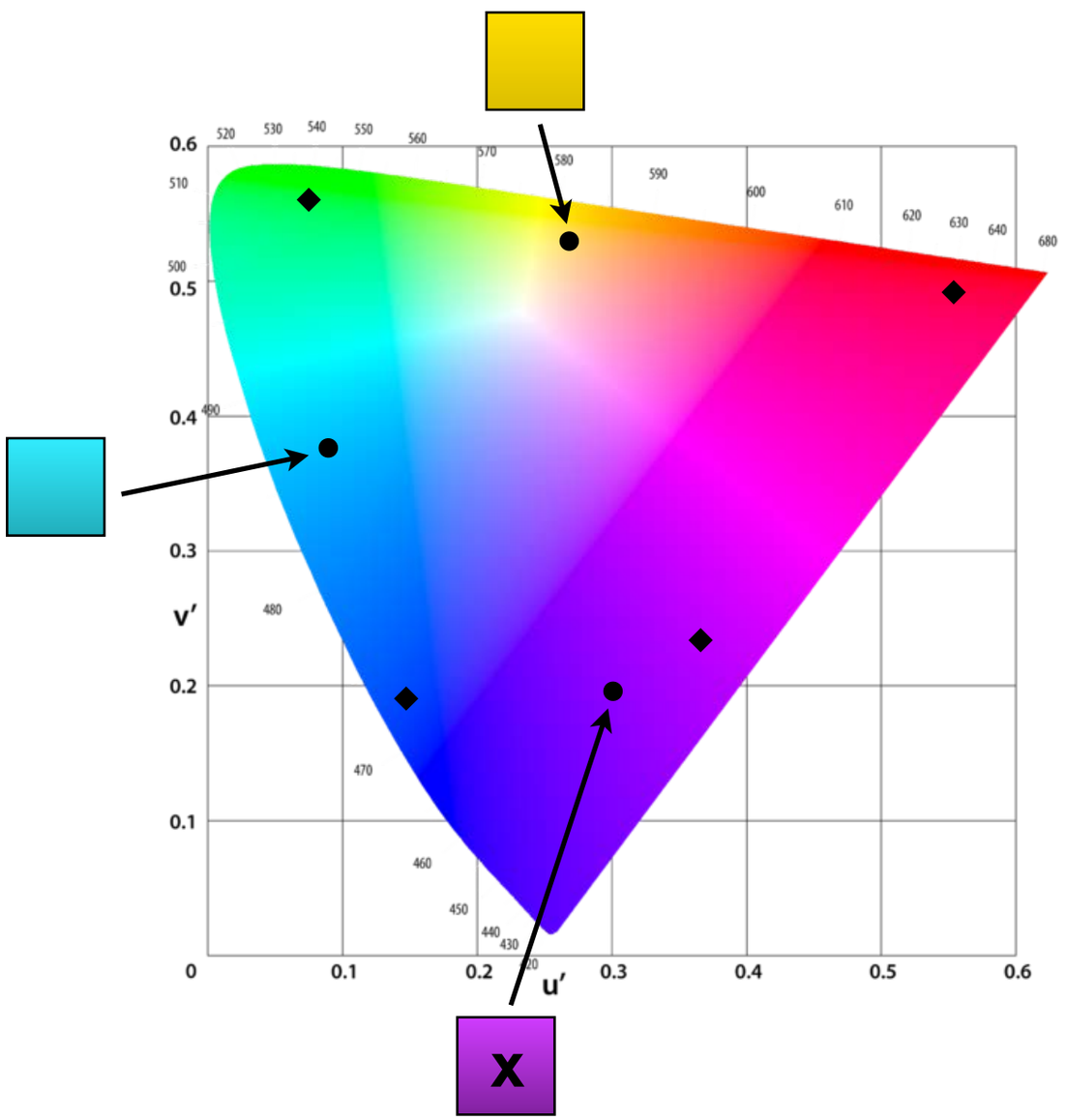

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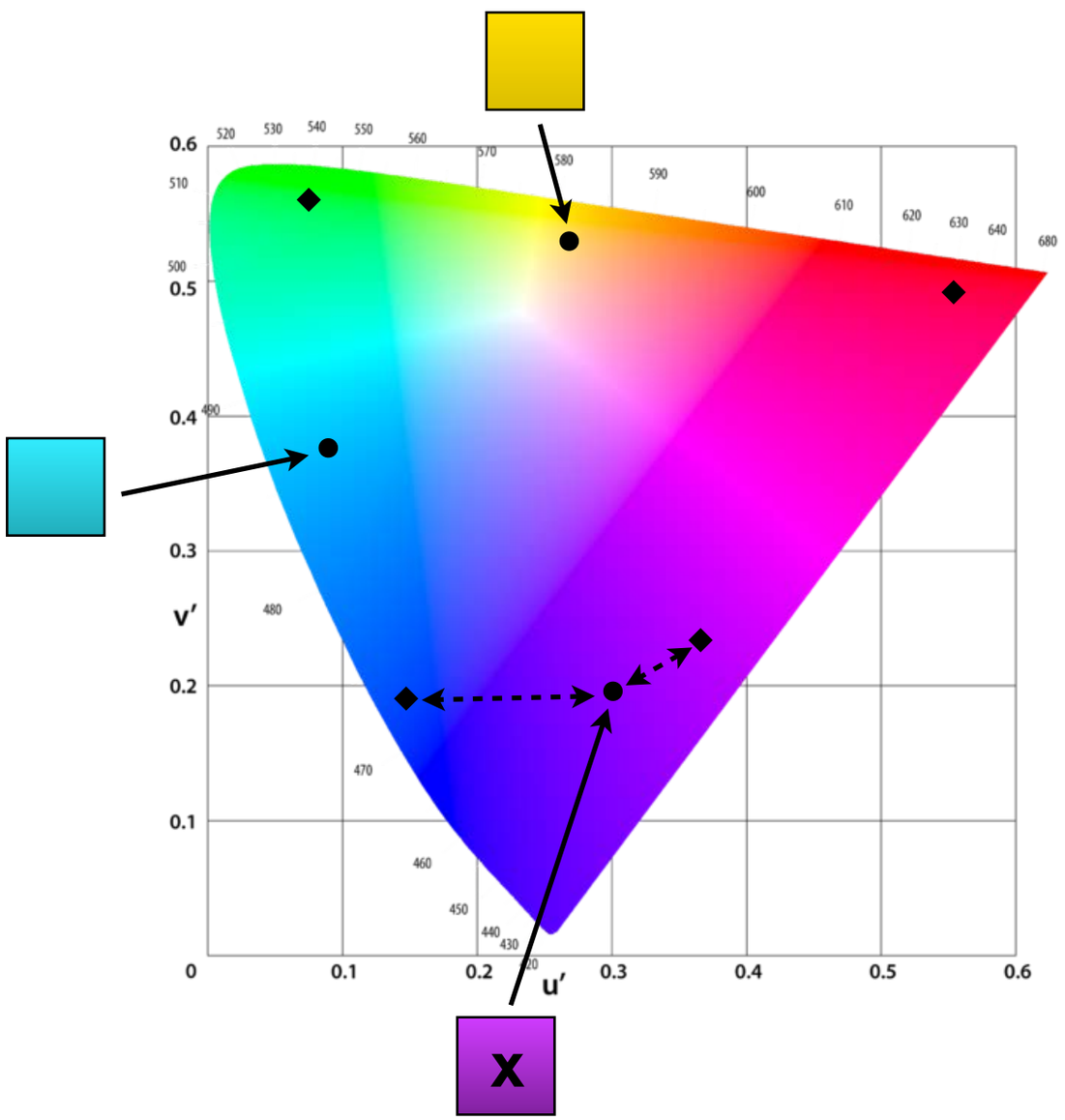

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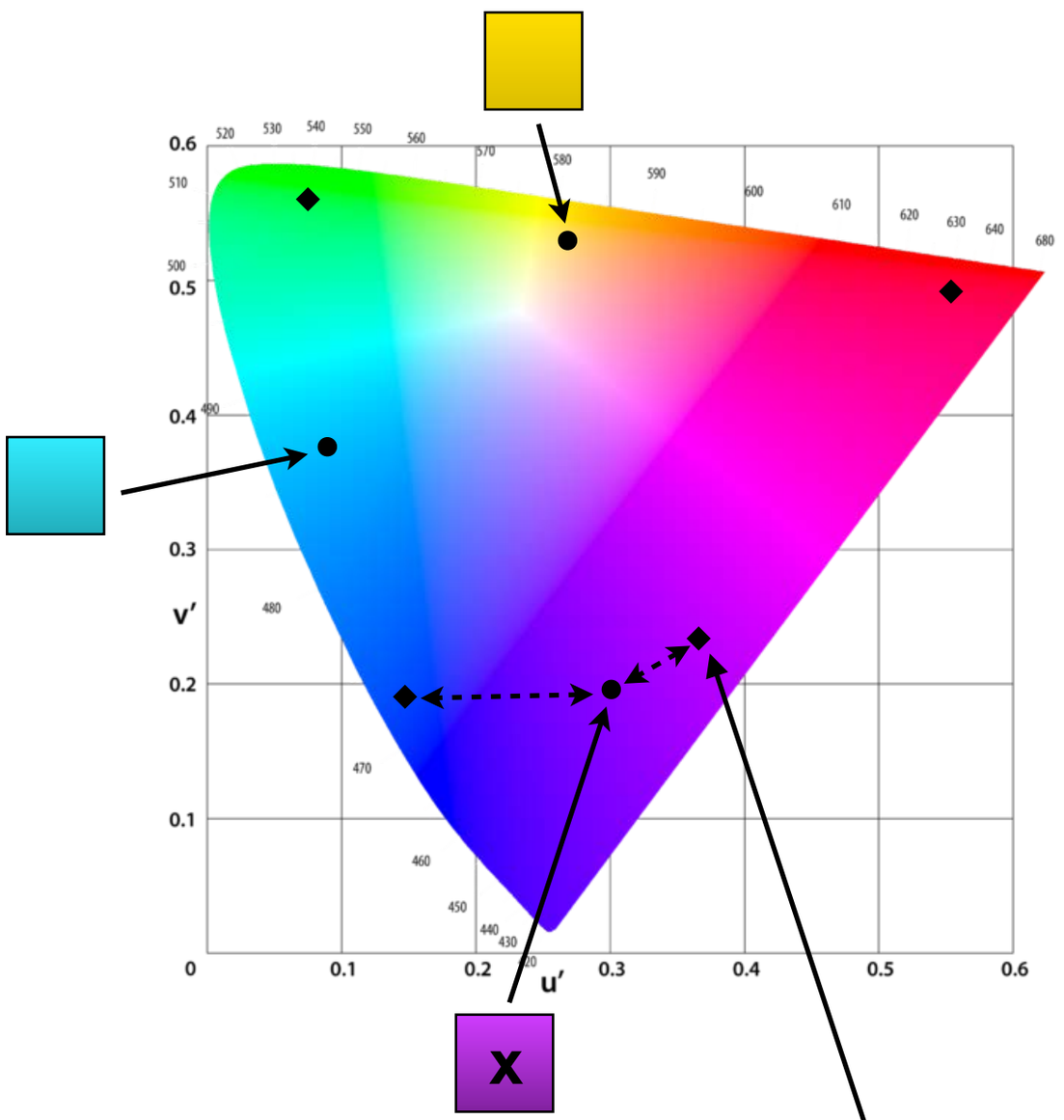

“wabado”

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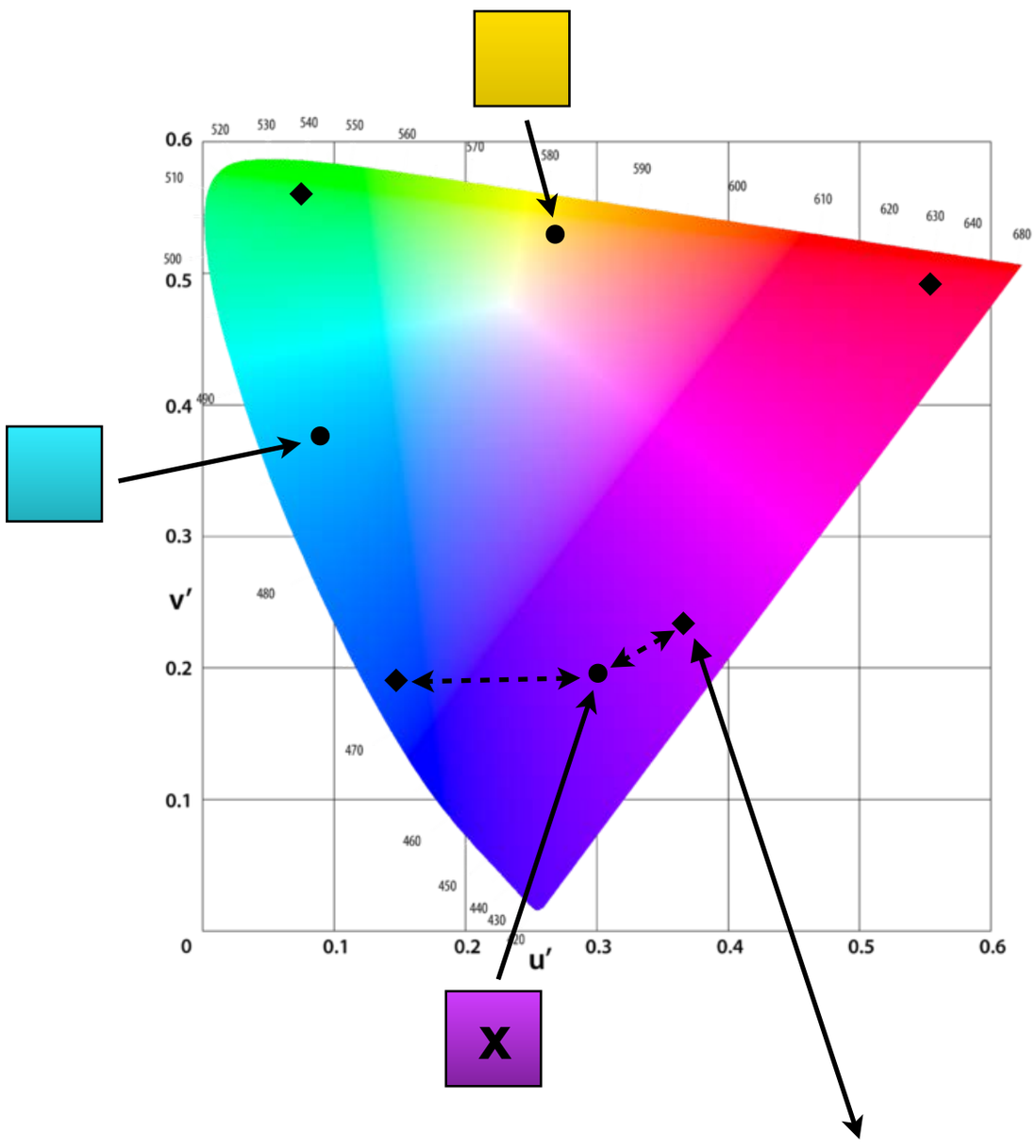
Full Colour Space Strategy: production & interpretation



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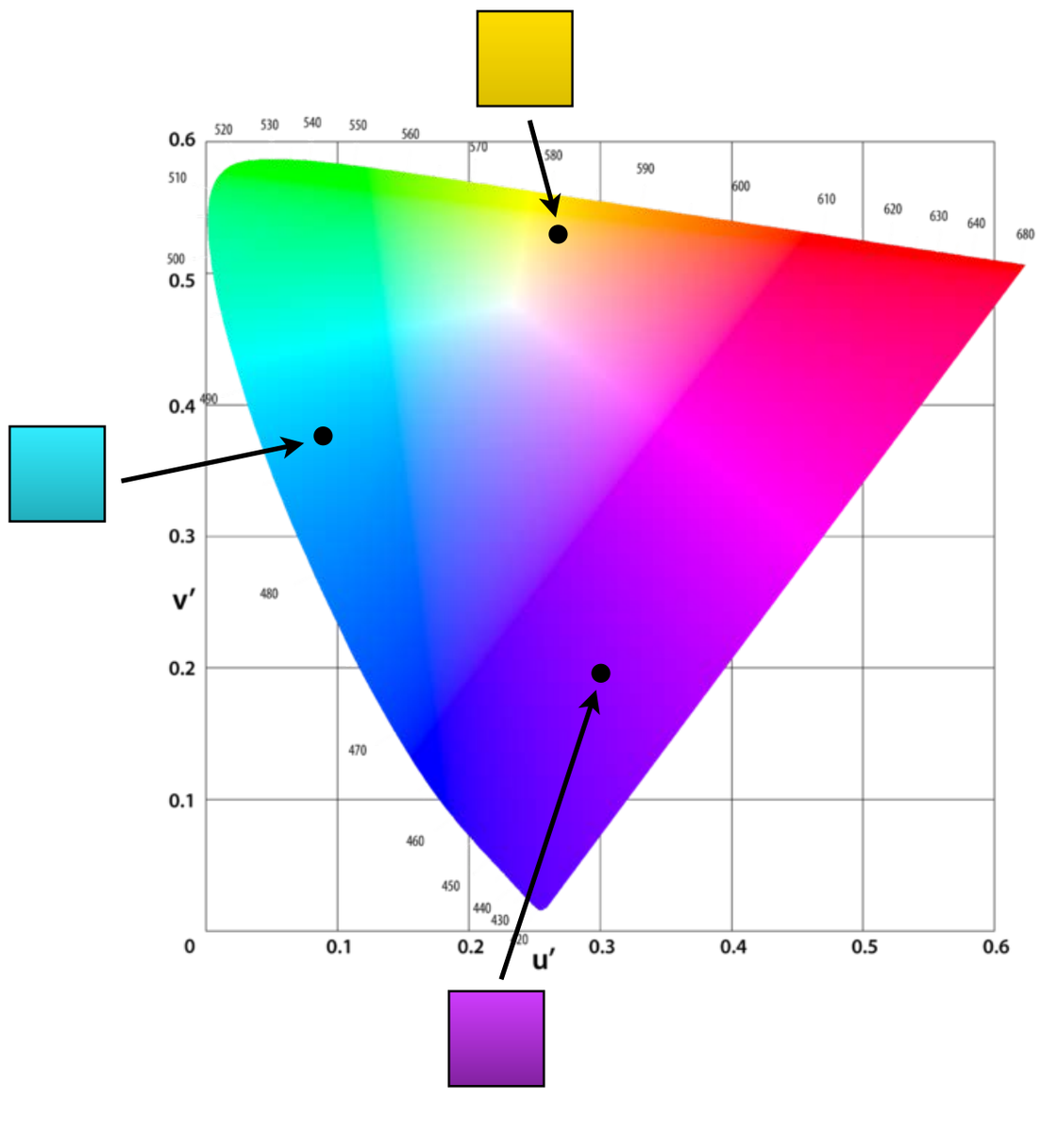

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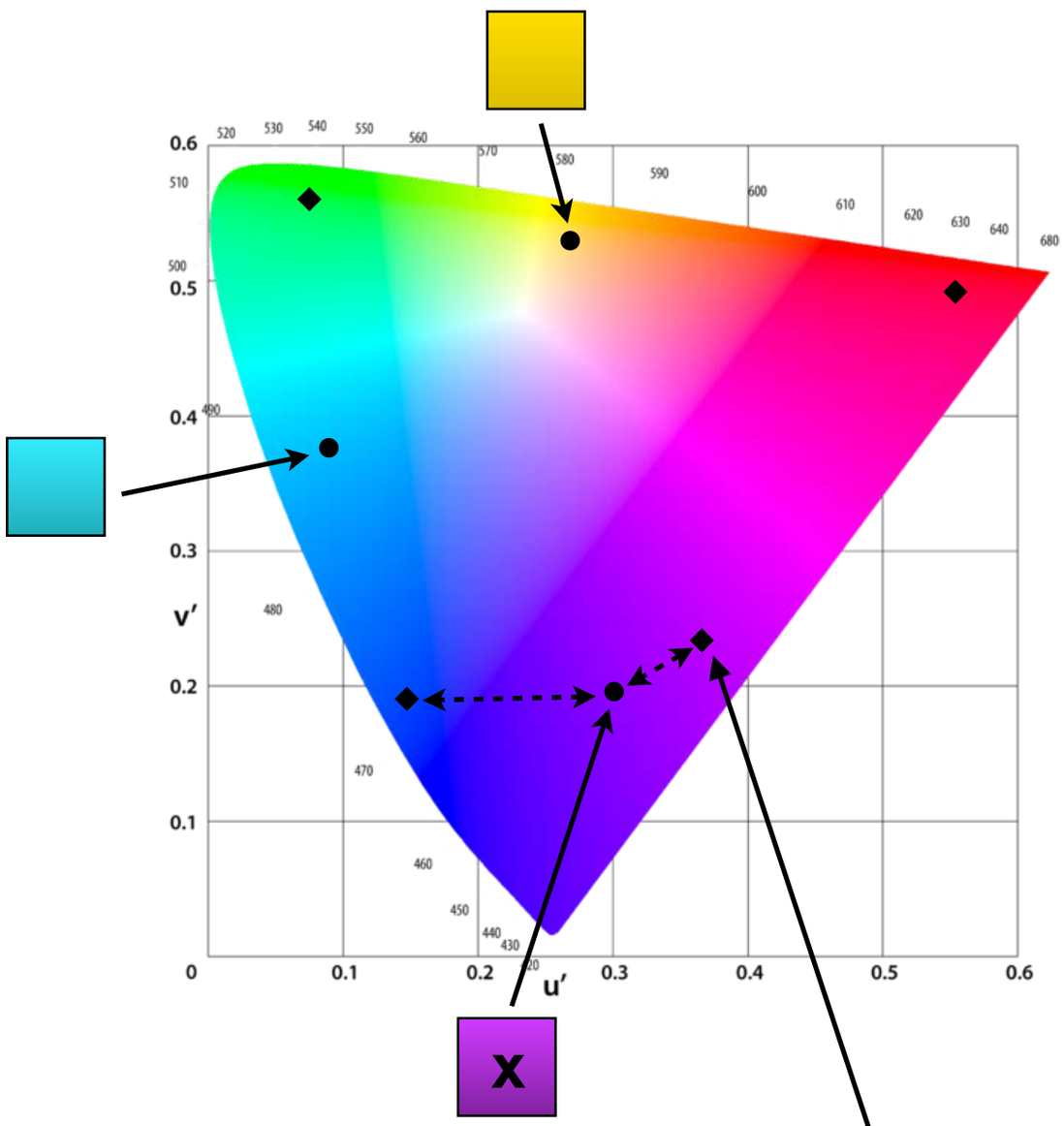
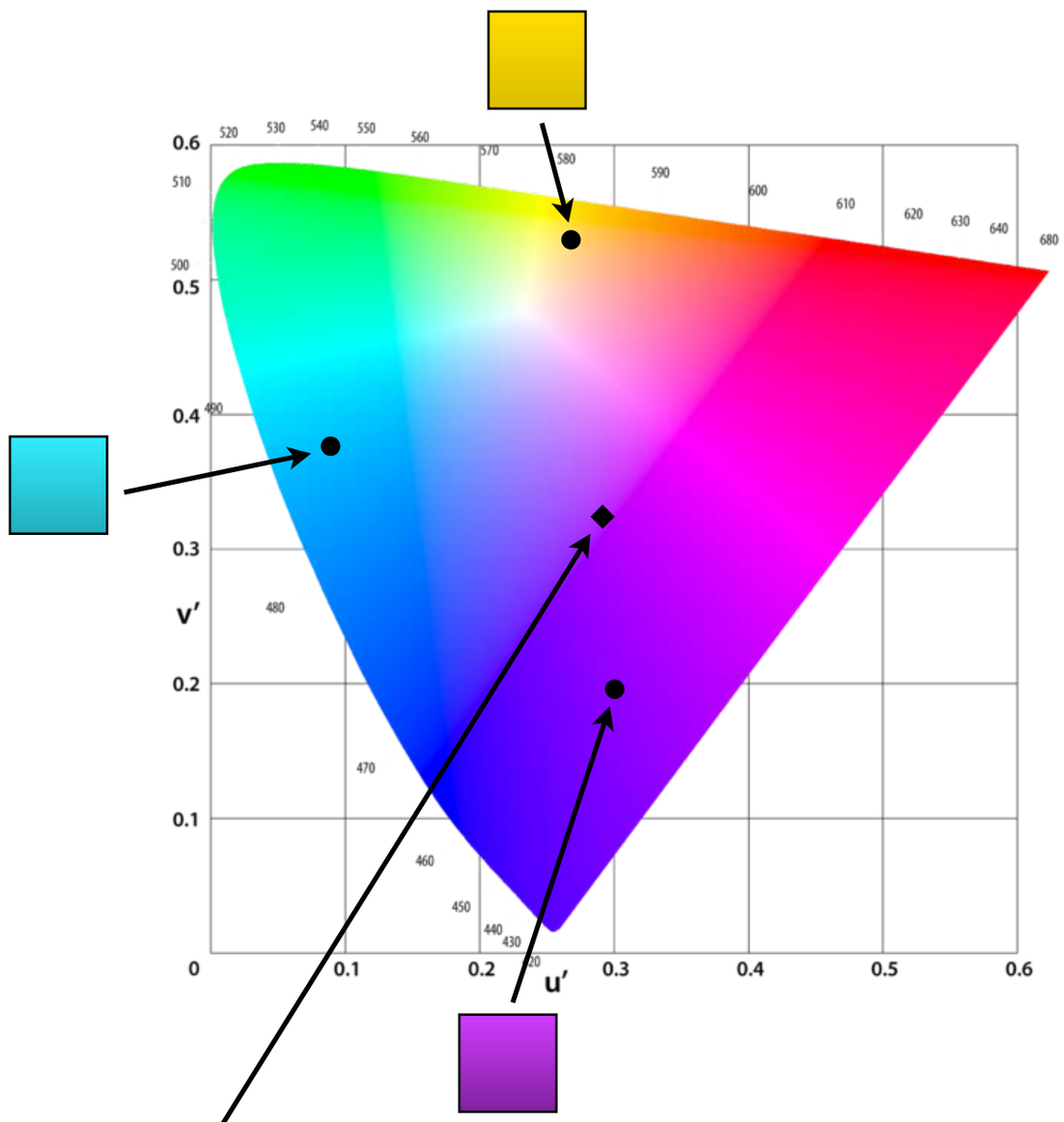
Full Colour Space Strategy: production & interpretation



“wabado”



“wabado”

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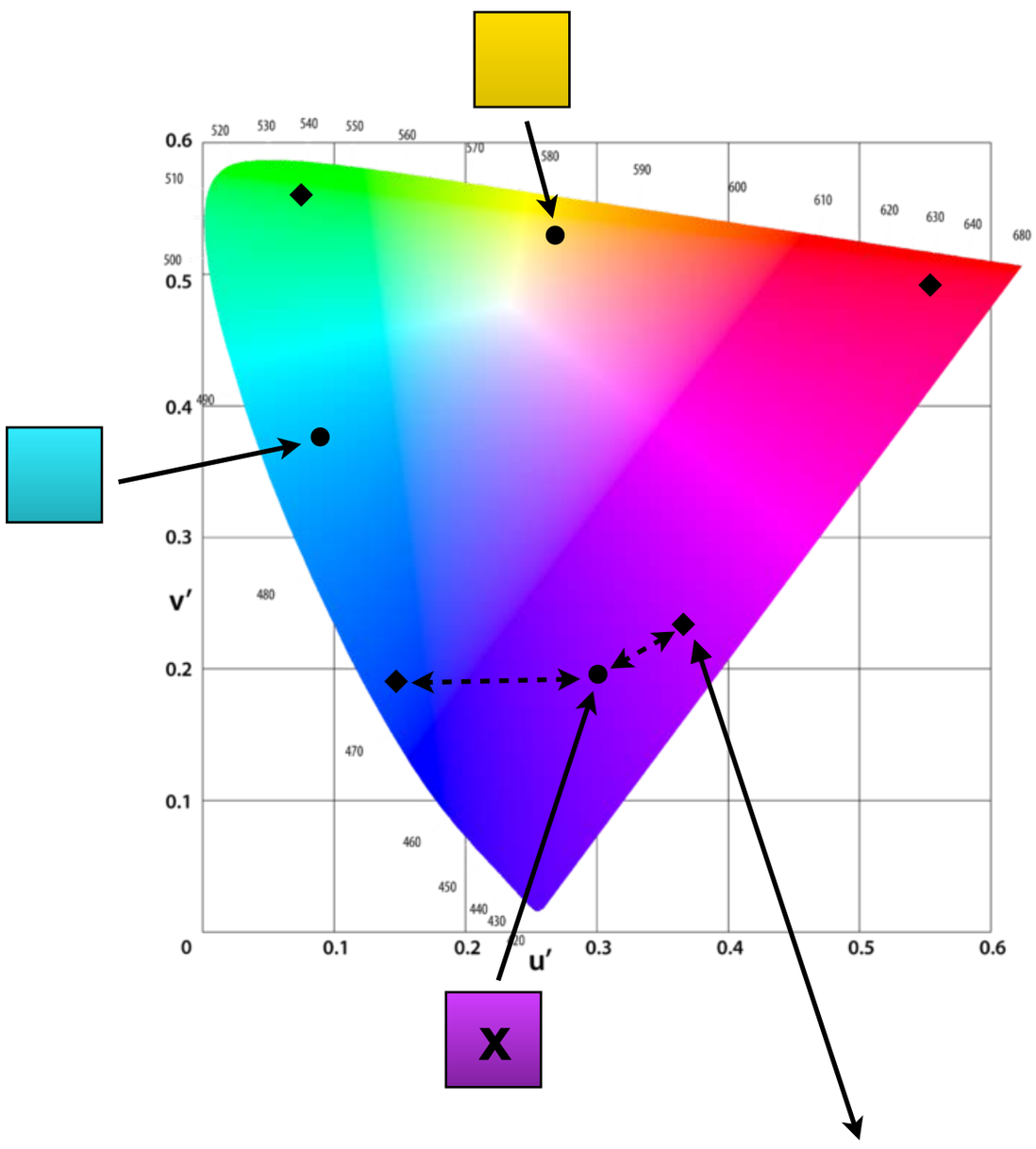
Full Colour Space Strategy: production & interpretation



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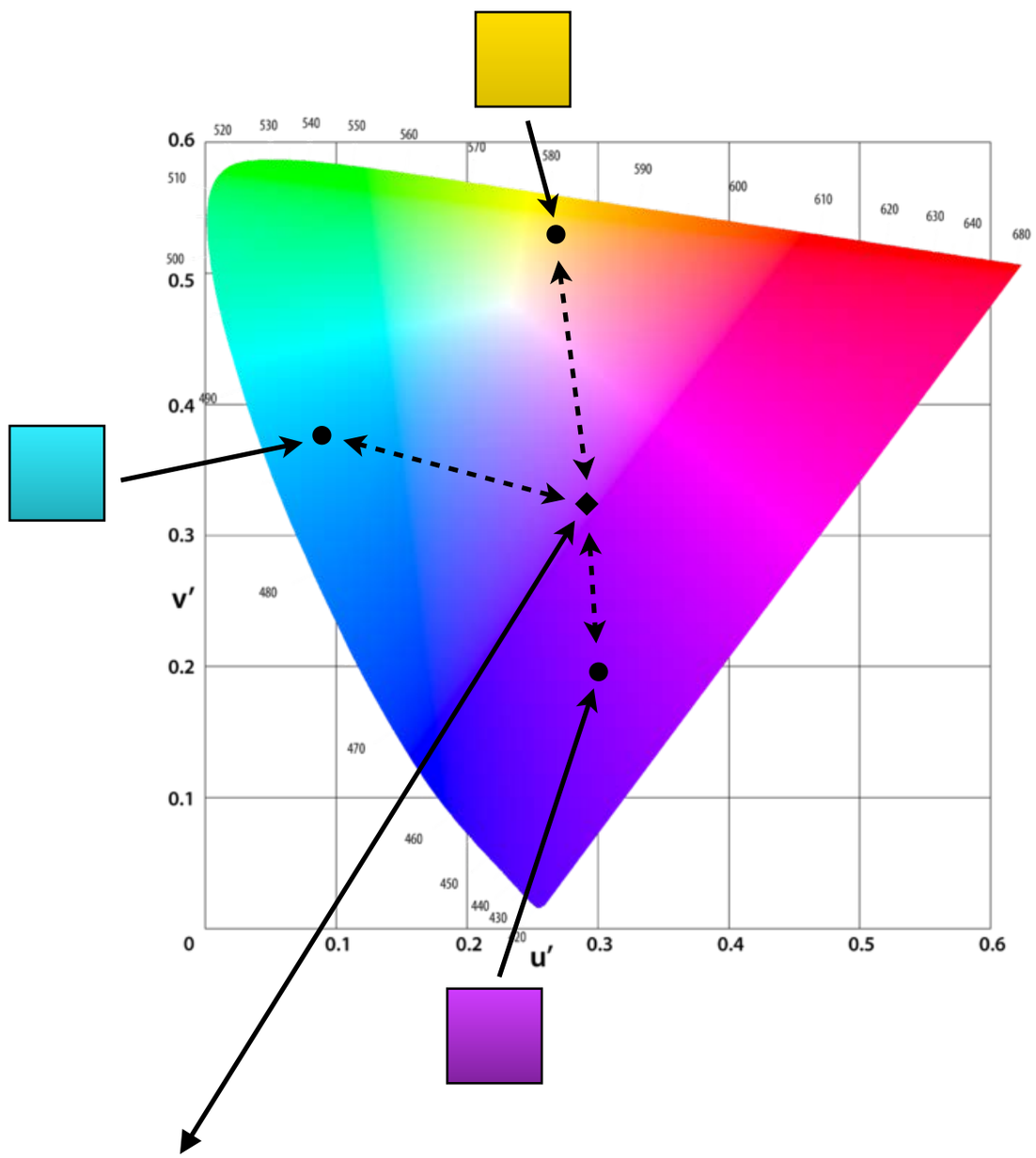

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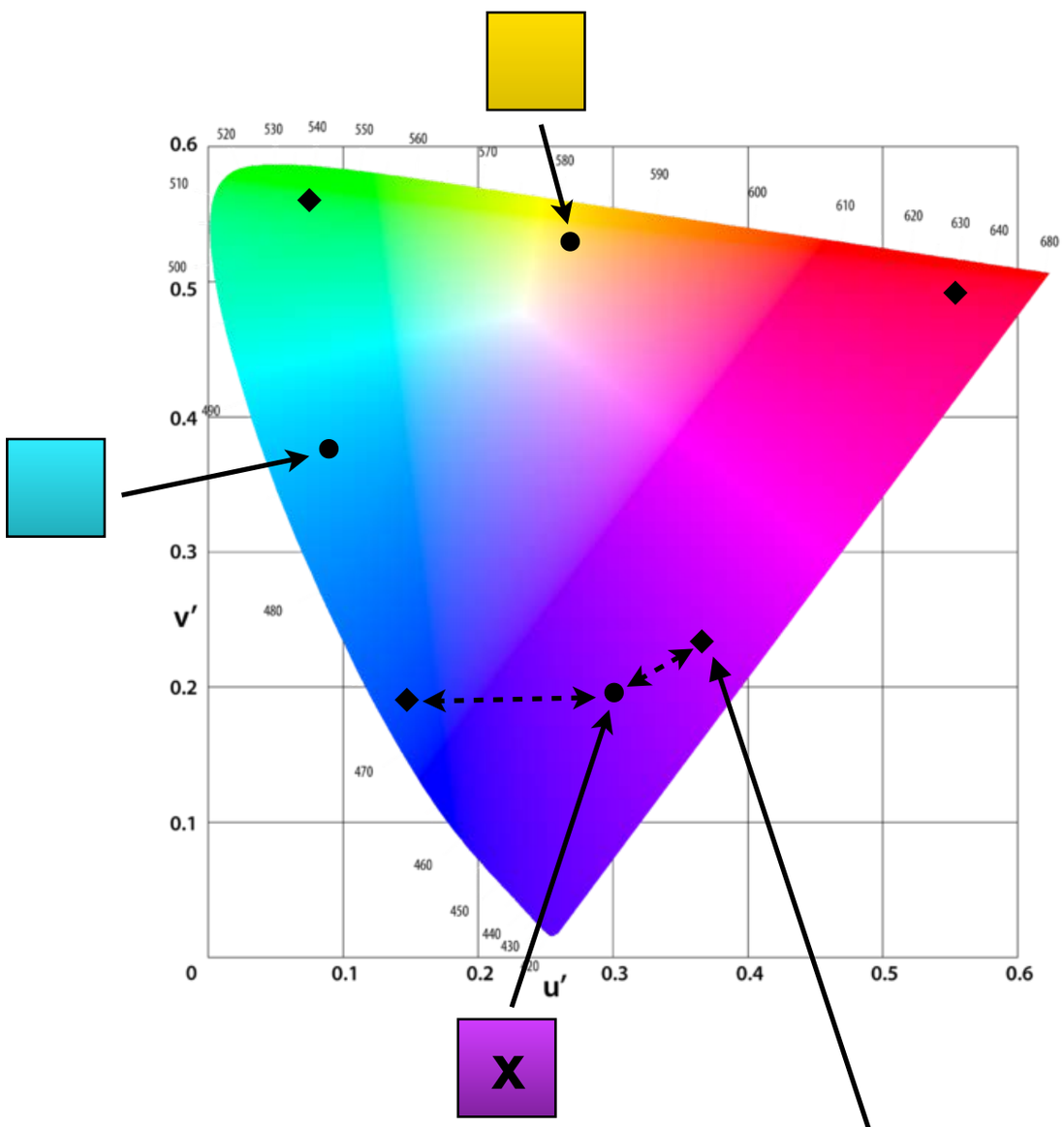
Full Colour Space Strategy: production & interpretation



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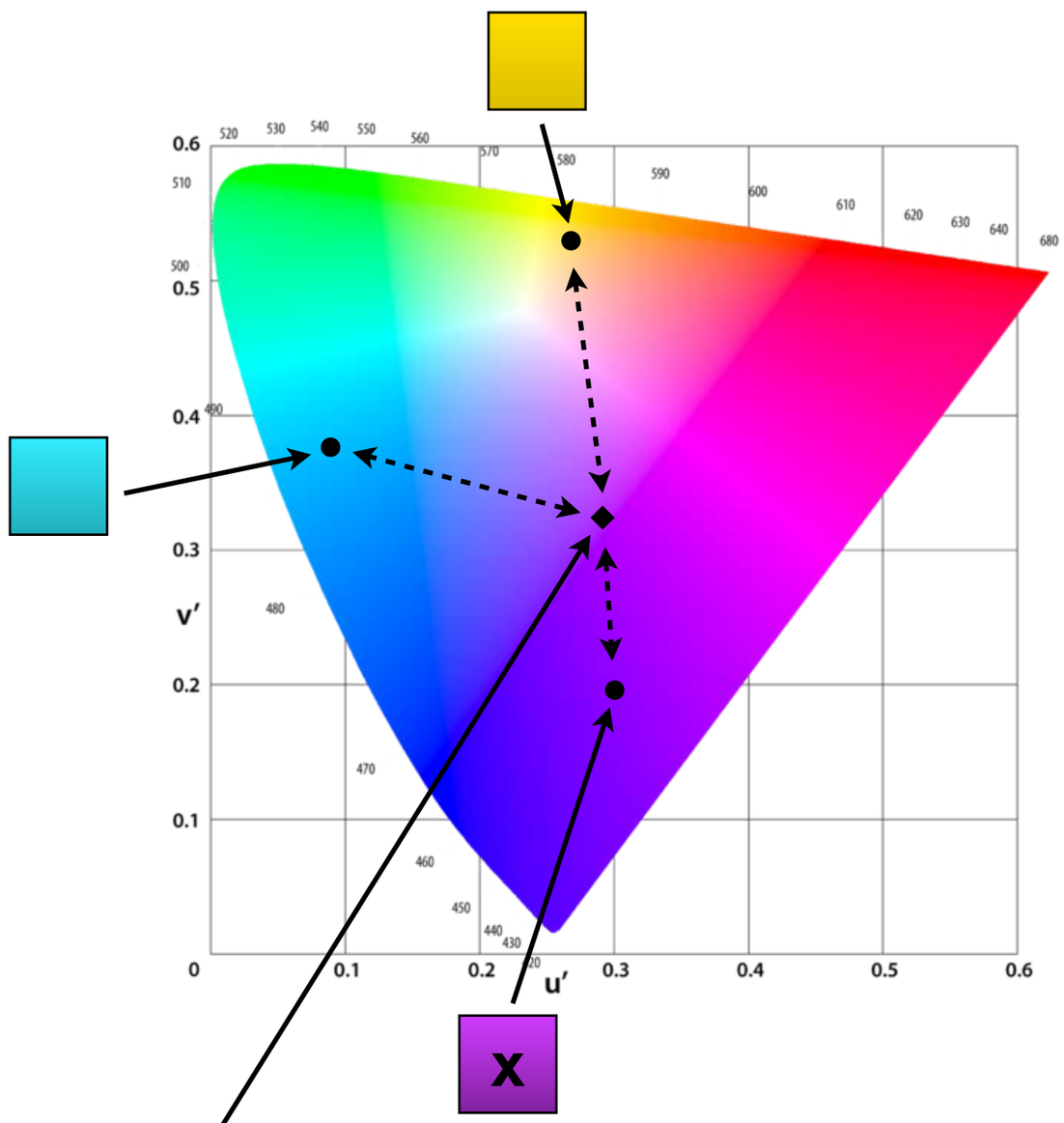

“wabado”

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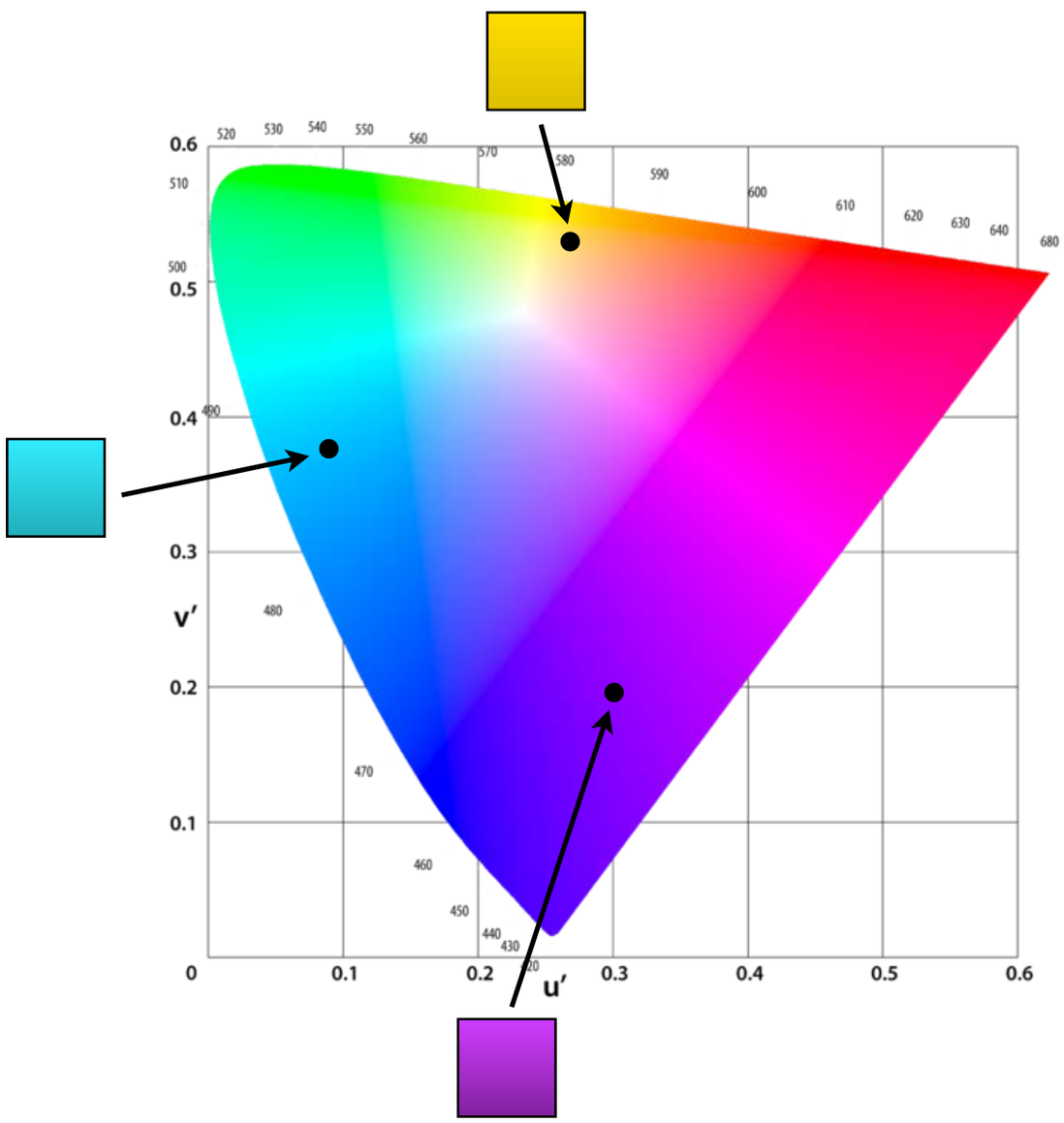
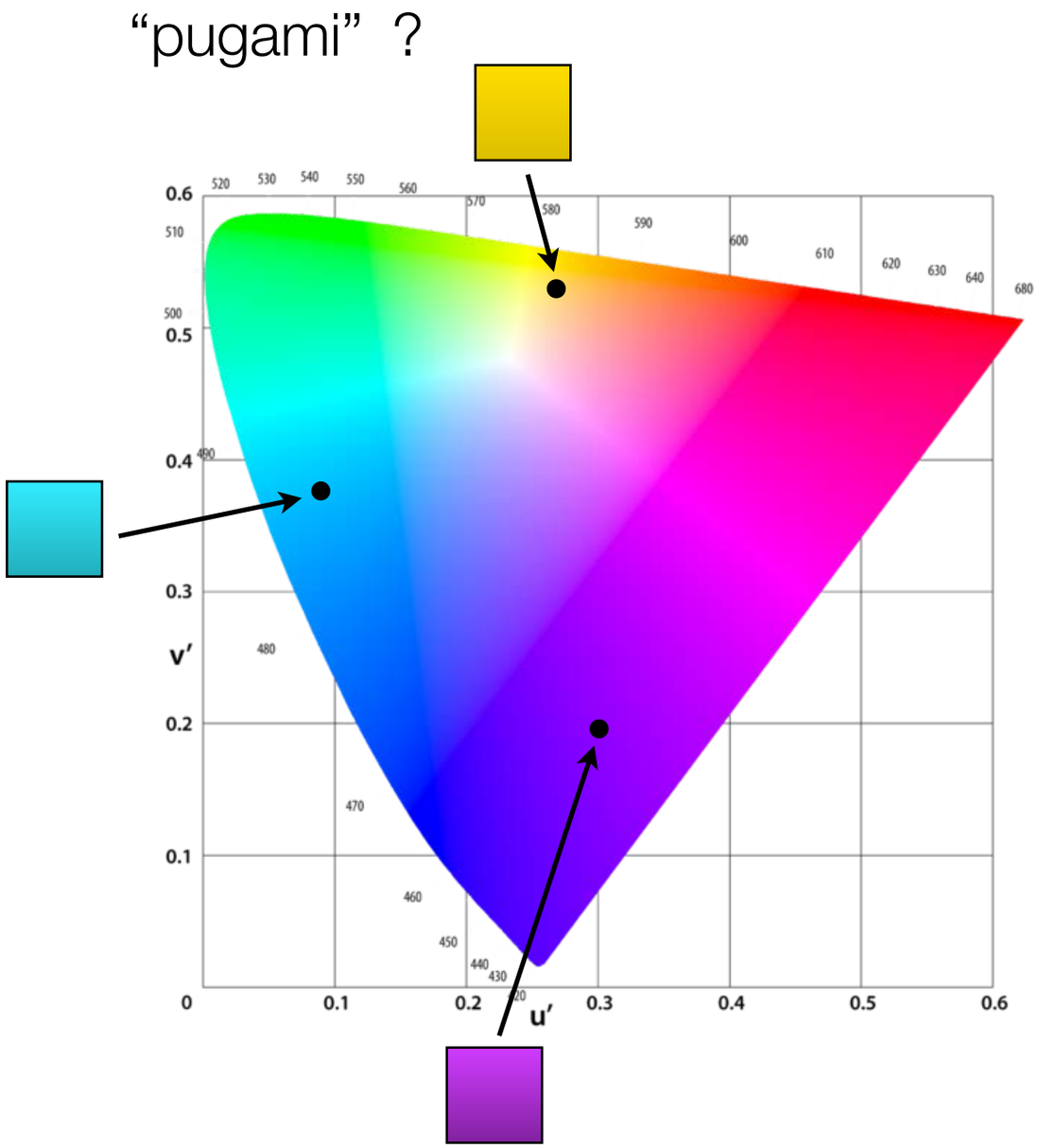
Full Colour Space Strategy: adoption & alignment



Belpaeme, T. and Bleys, J. (2005) Explaining Universal Color Categories Through a Constrained Acquisition Process. Adaptive Behaviour **13**(4), 293-310

Full Colour Space Strategy: adoption & alignment

“pugami” ?



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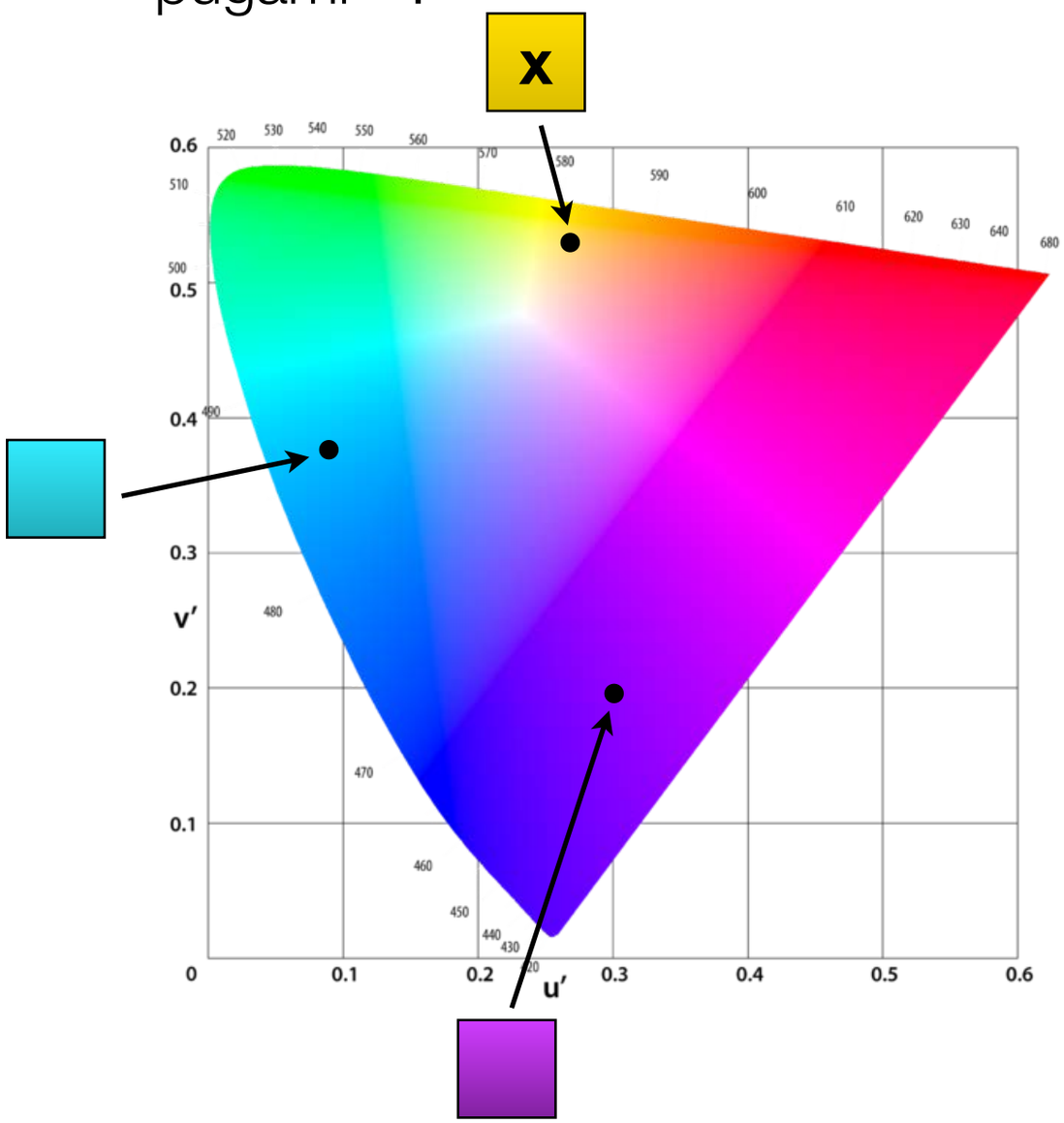
Full Colour Space Strategy: adoption & alignment

“pugami” ?



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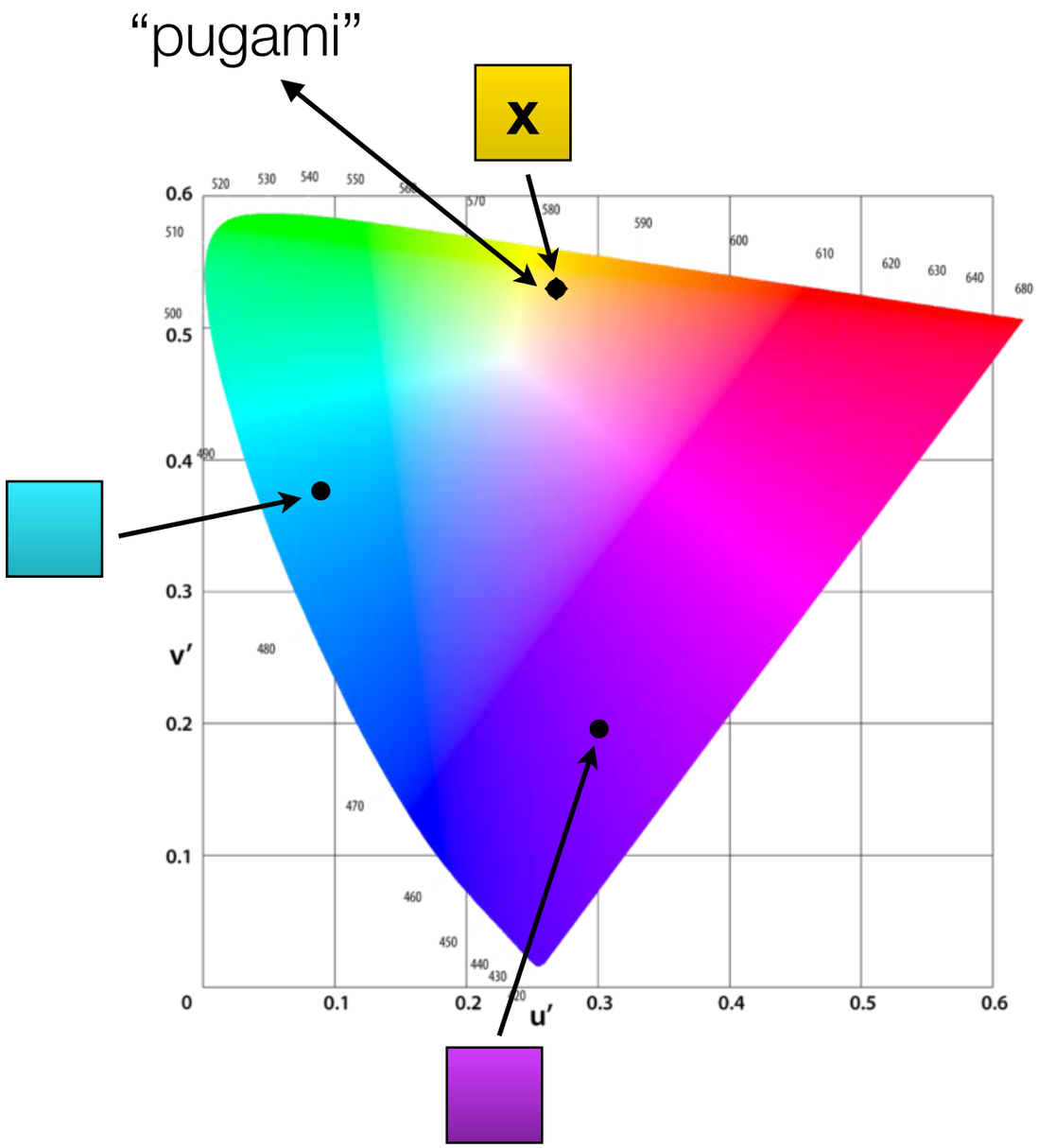
Full Colour Space Strategy: adoption & alignment



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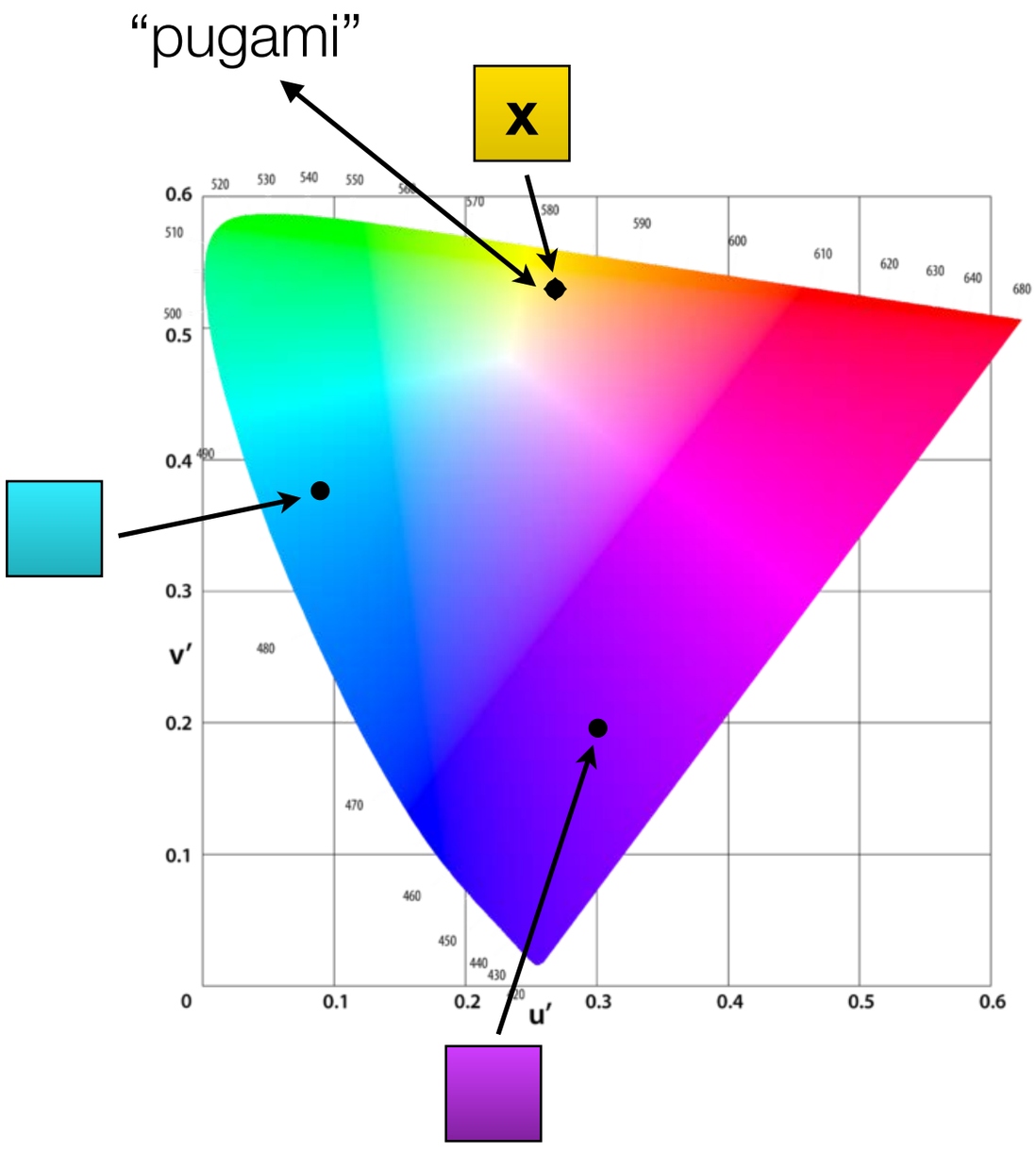
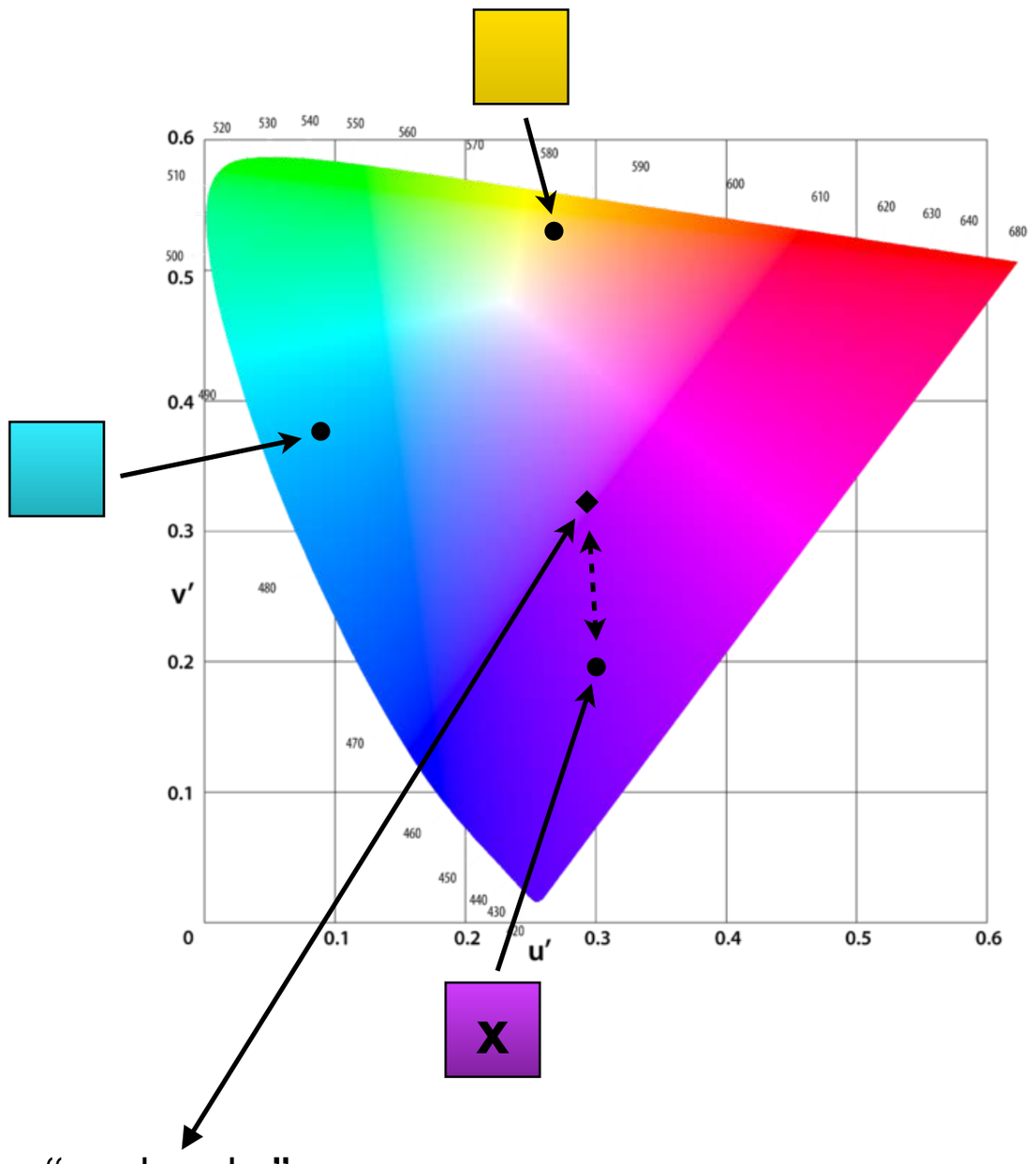
Full Colour Space Strategy: adoption & alignment





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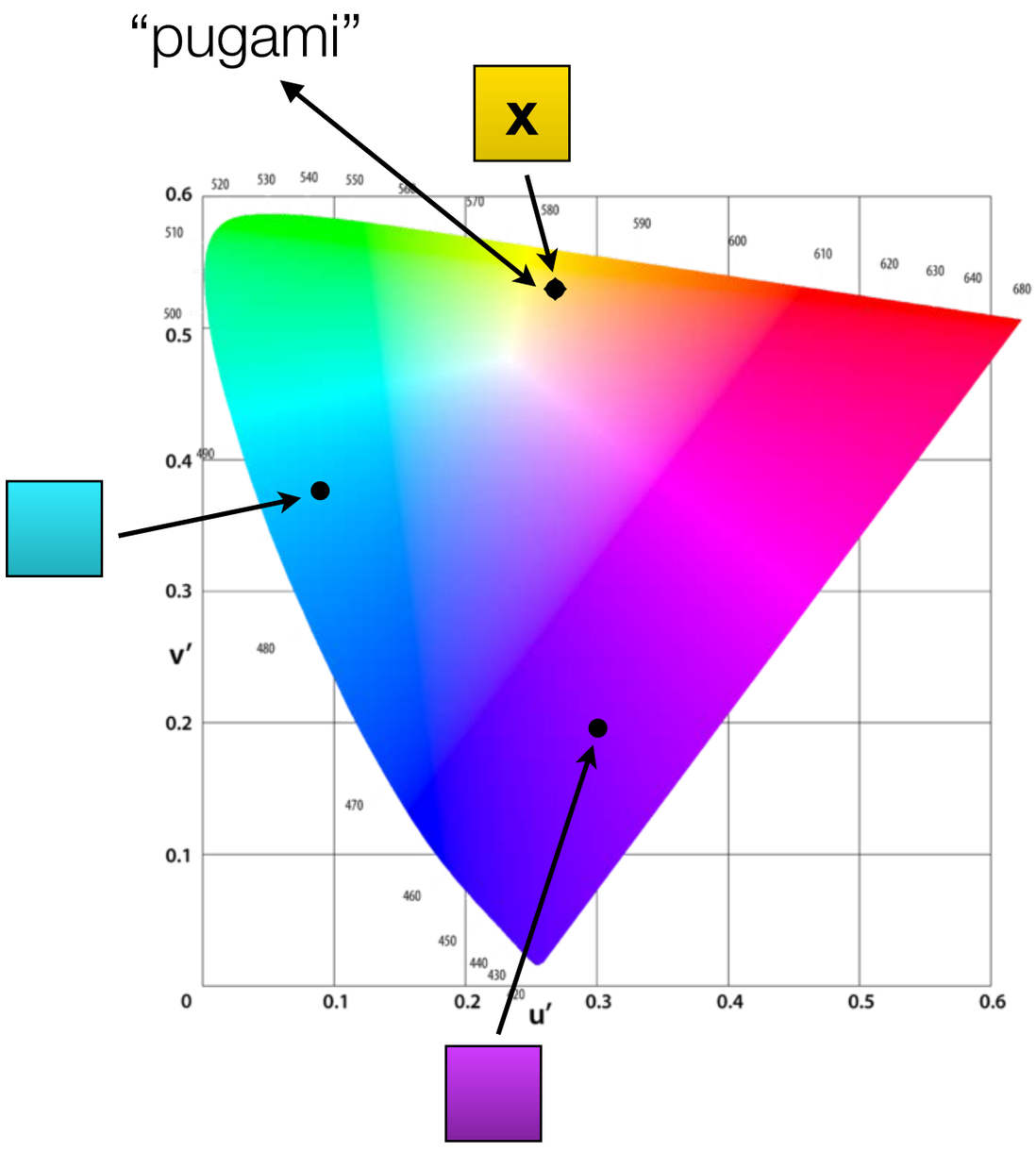
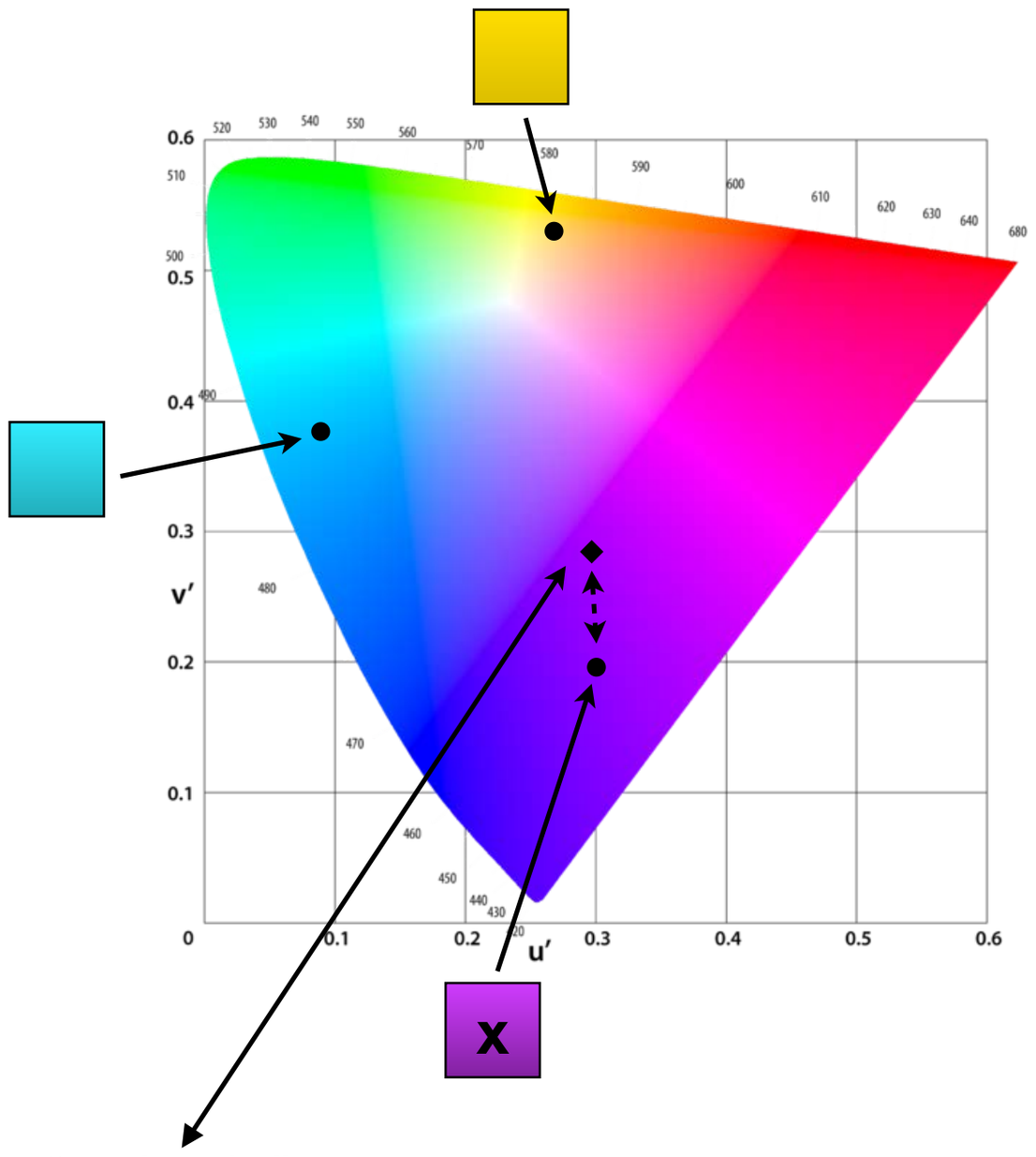
Full Colour Space Strategy: adoption & alignment





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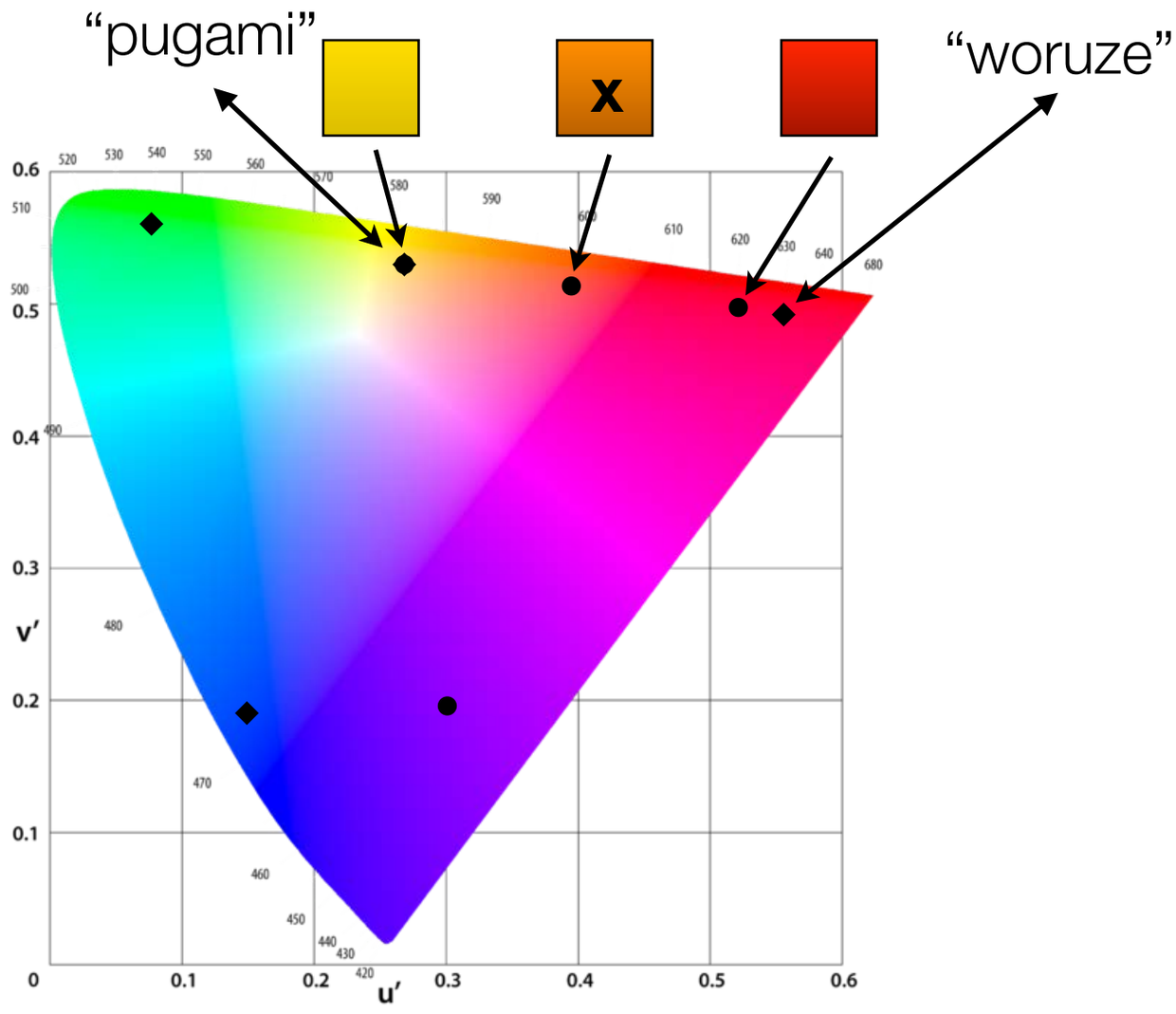
Full Colour Space Strategy: expansion



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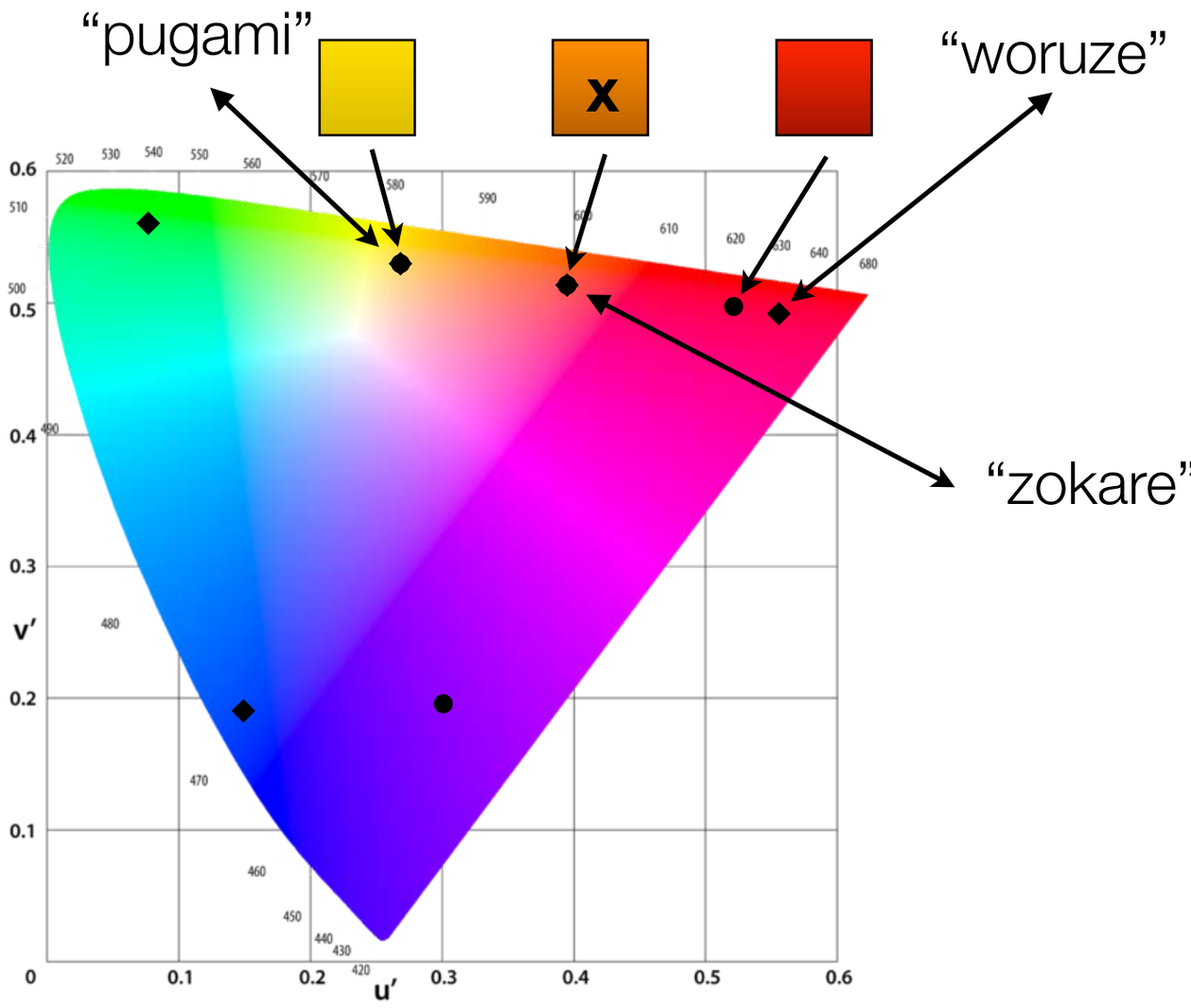
Full Colour Space Strategy: expansion



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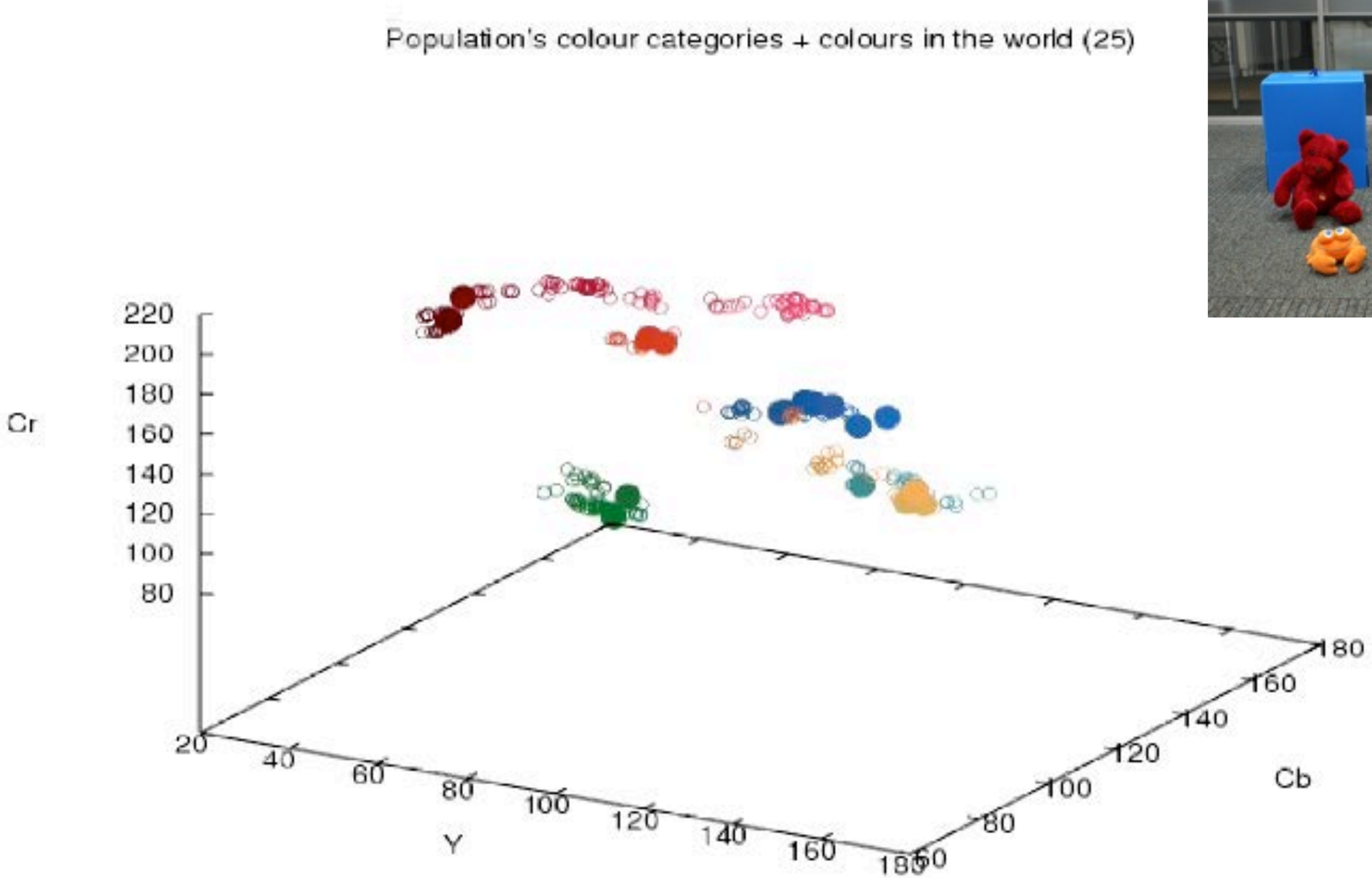
Full Colour Space Strategy: evolving category system

Bleys, J., Loetzsch, M., Spranger, M. and Steels, L. (2009) The Grounded Colour Naming Game. Proceedings of 18th IEEE International Symposium on Robot and Human Interactive Communication (Ro-Man 2009).

Full Colour Space Strategy: evolving category system



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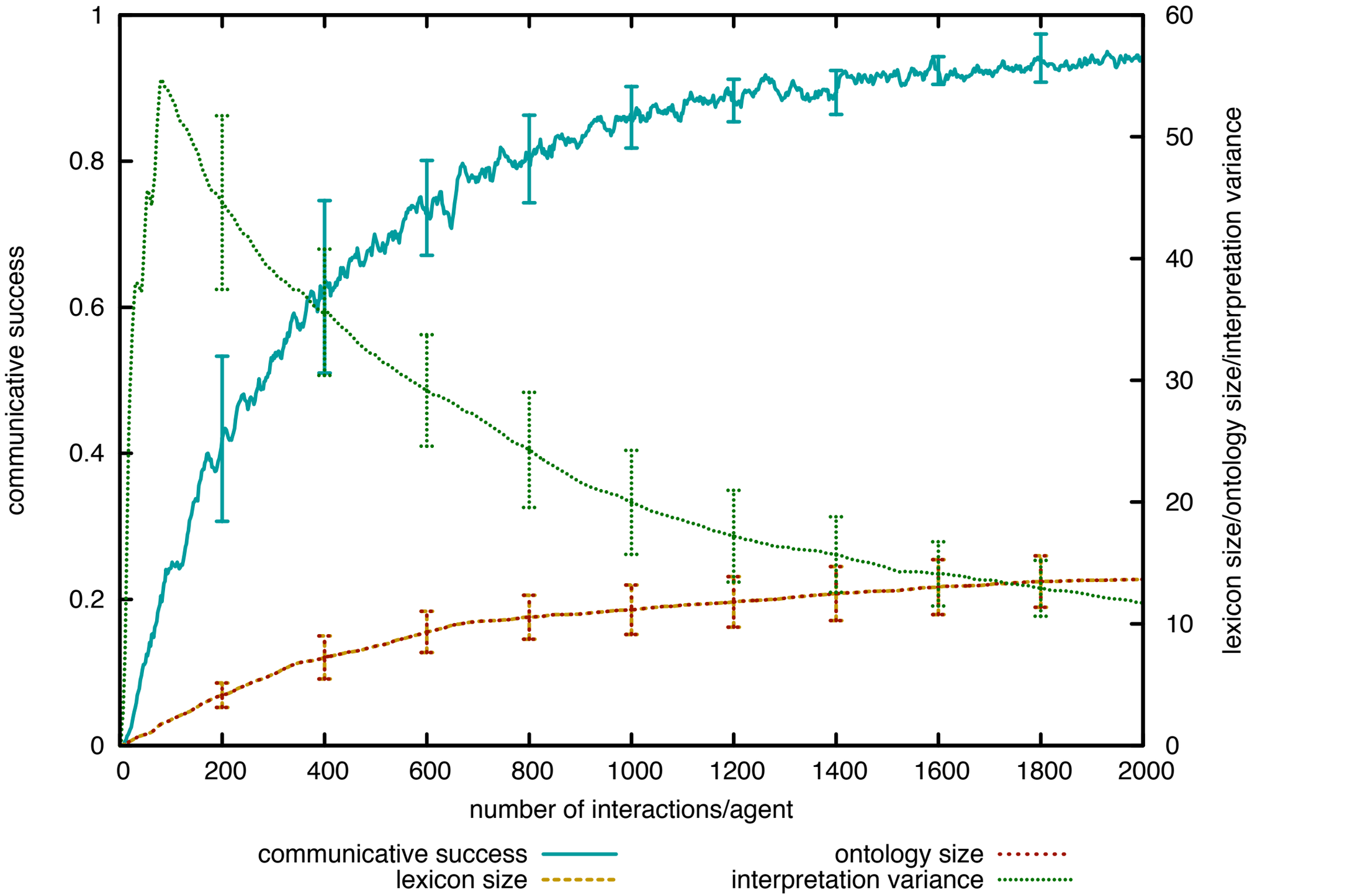
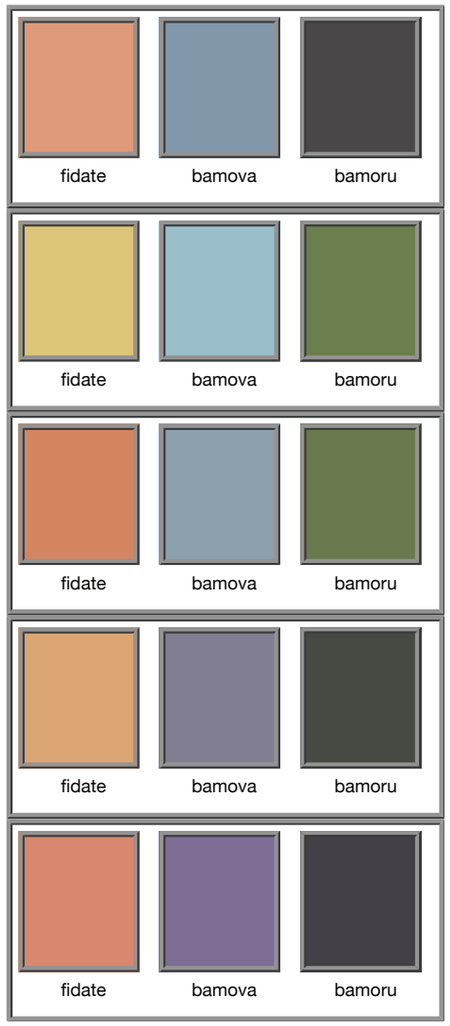
Full Colour Space Strategy: resulting dynamics



Bleys, J. and Steels, L. (2009) Linguistic Selection of Language Strategies: A Case Study for Colour. Proceedings of ECAL09.

Full Colour Space Strategy: evolving colour system



1000

3000

colour lexicon after X interactions

Bleys, J. and Steels, L. (2009) Linguistic Selection of Language Strategies: A Case Study for Colour. Proceedings of ECAL09.

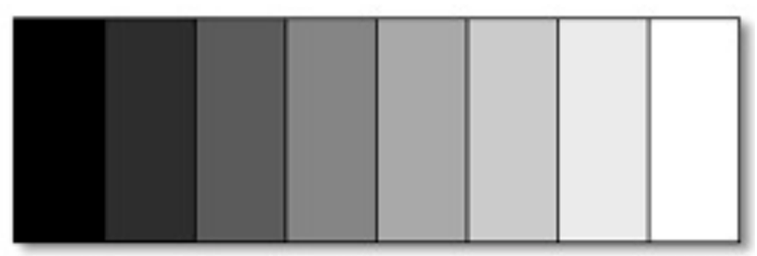
Brightness Strategy

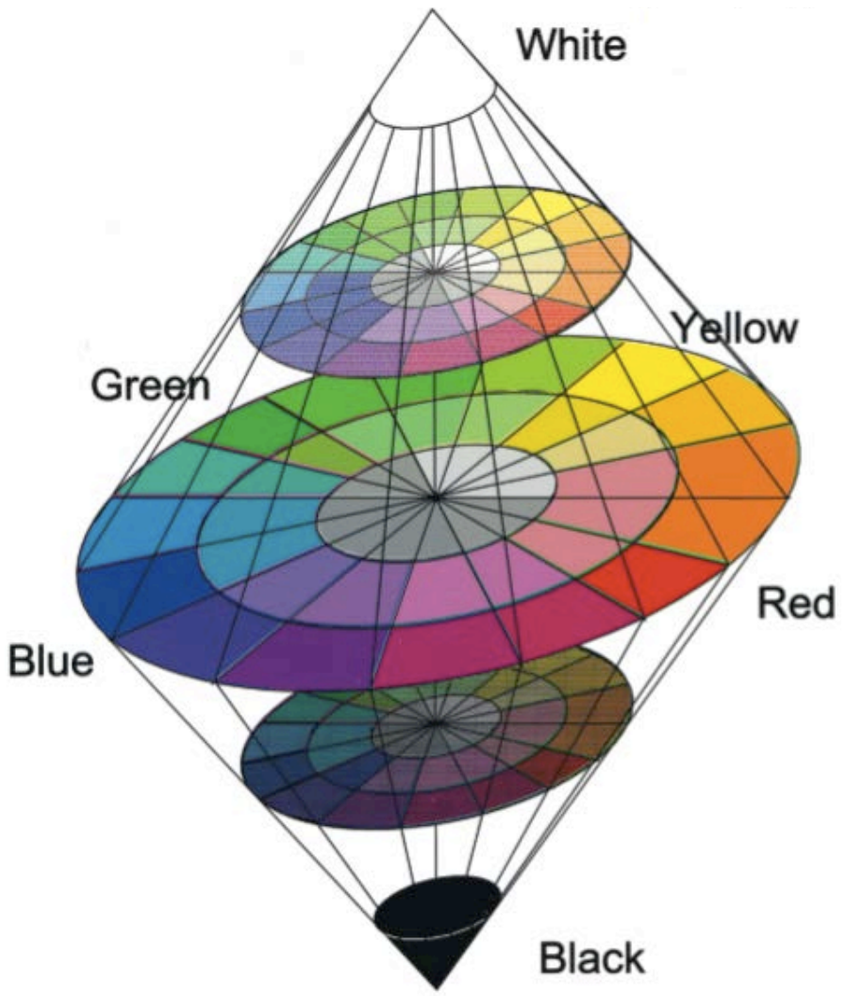
- instead of using 3 dimensions (*L*u*v**) of colour space, the prototypes only specify value on lightness channel (*L**)

- similar production/interpretation functions

- similar adoption/alignment functions

- similar expansion function





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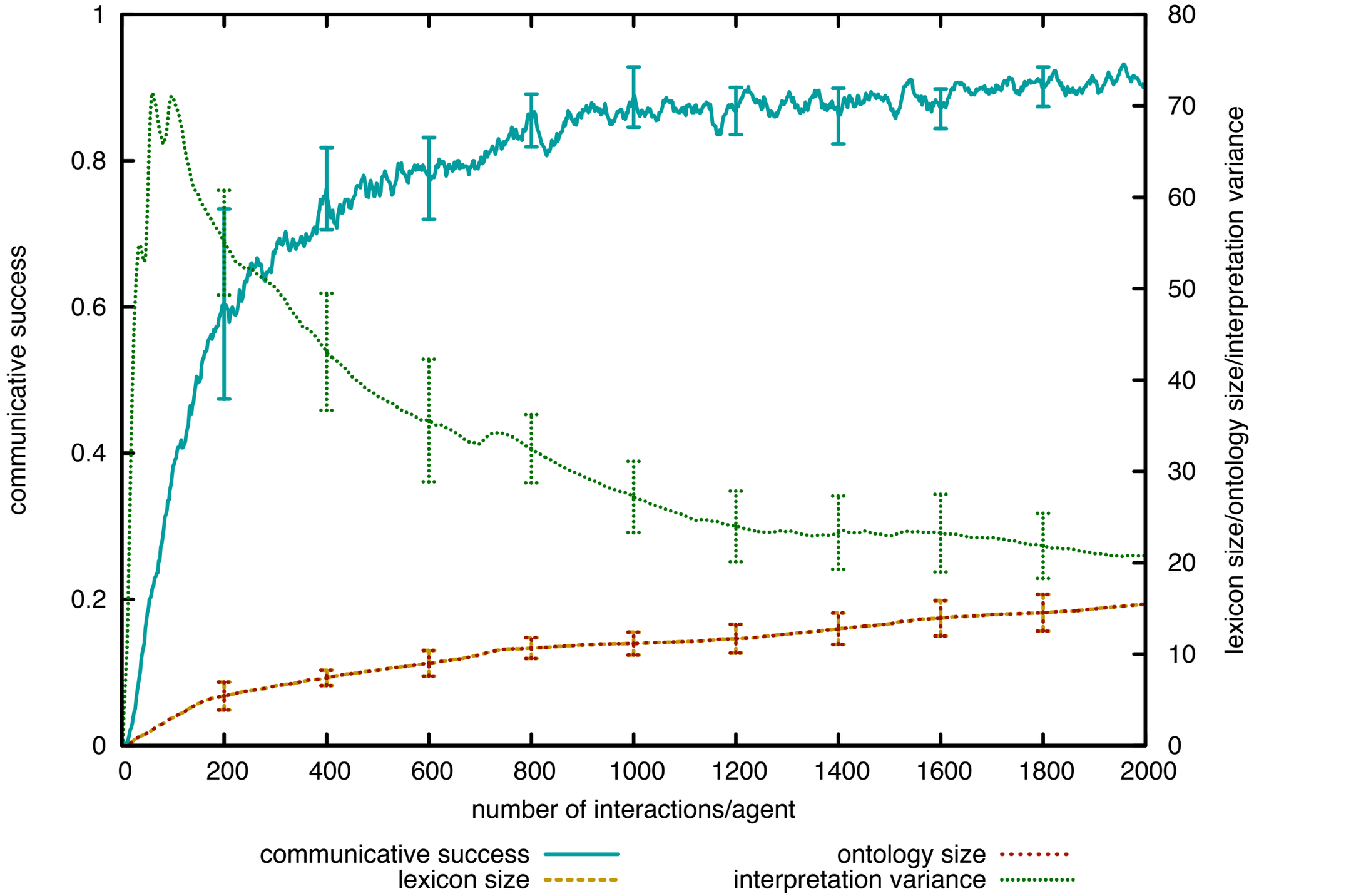
Brightness Strategy: resulting dynamics



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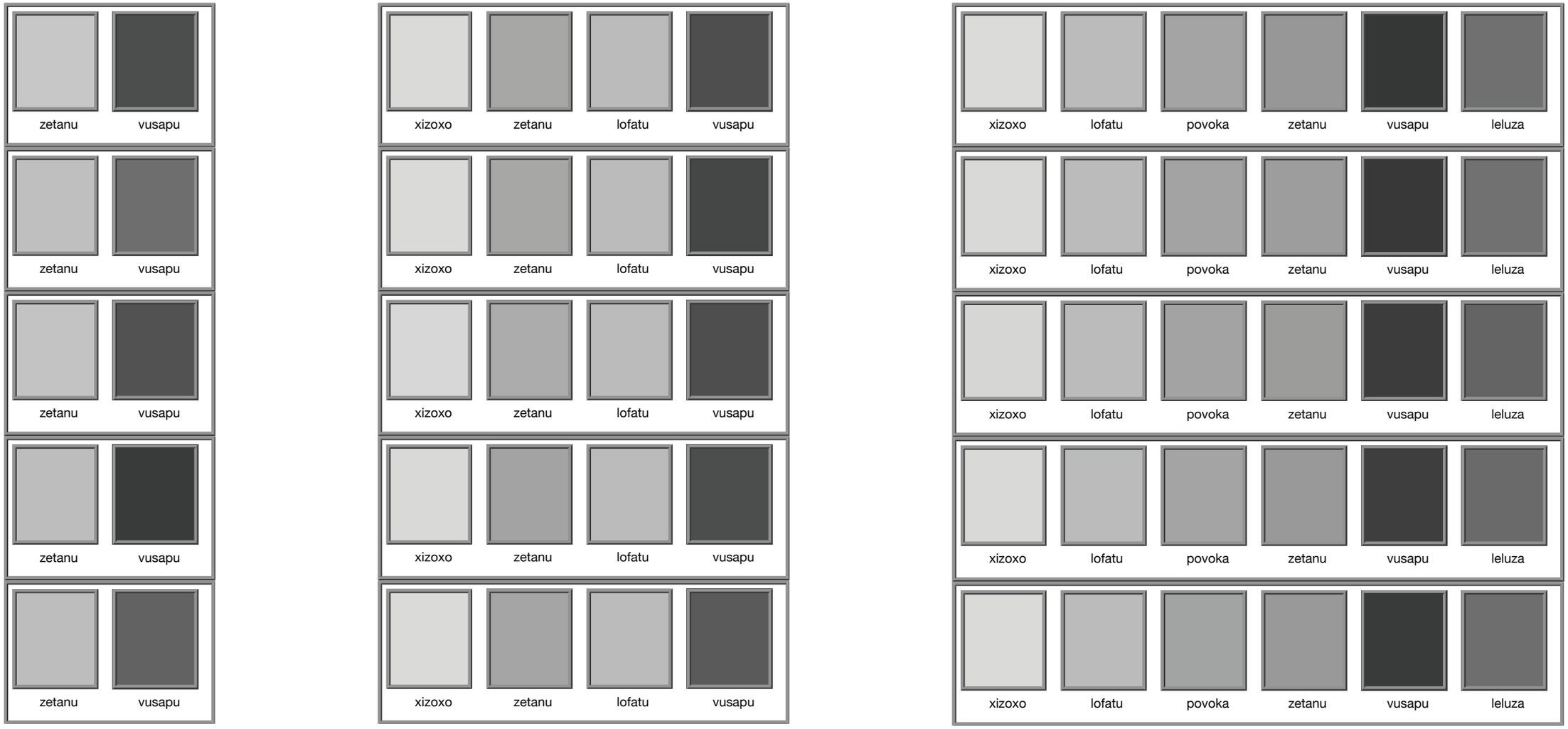
Brightness Strategy: evolving language system



1000 3000 4000

colour lexicon after X interactions

Bleys, J. and Steels, L. (2009) Linguistic Selection of Language Strategies: A Case Study for Colour. Proceedings of ECAL09.

Model

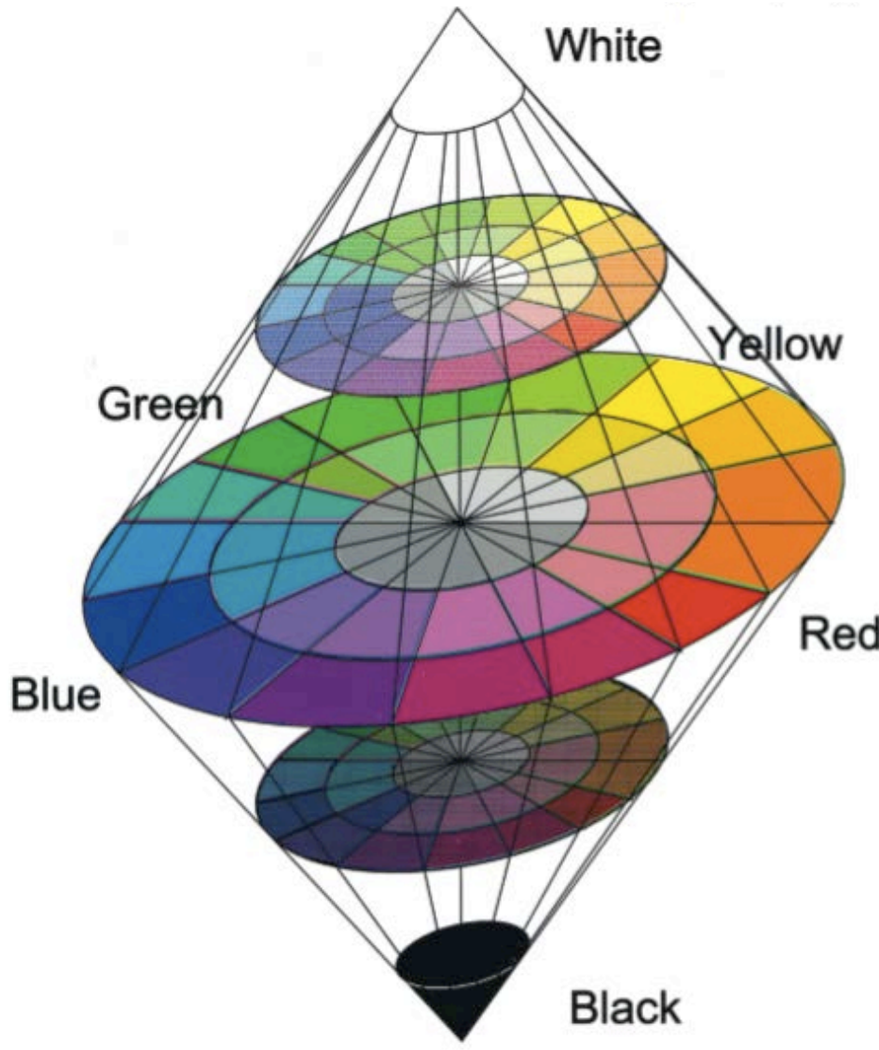
- design language game in which colour is functionally relevant

- each use of a colour category is operationalised as a different language strategy

  - brightness: only brightness (L^*) dimension of colour space is used

  - full colour space: all dimensions of the colour space are used

- **add layer of linguistic selection of language strategies**



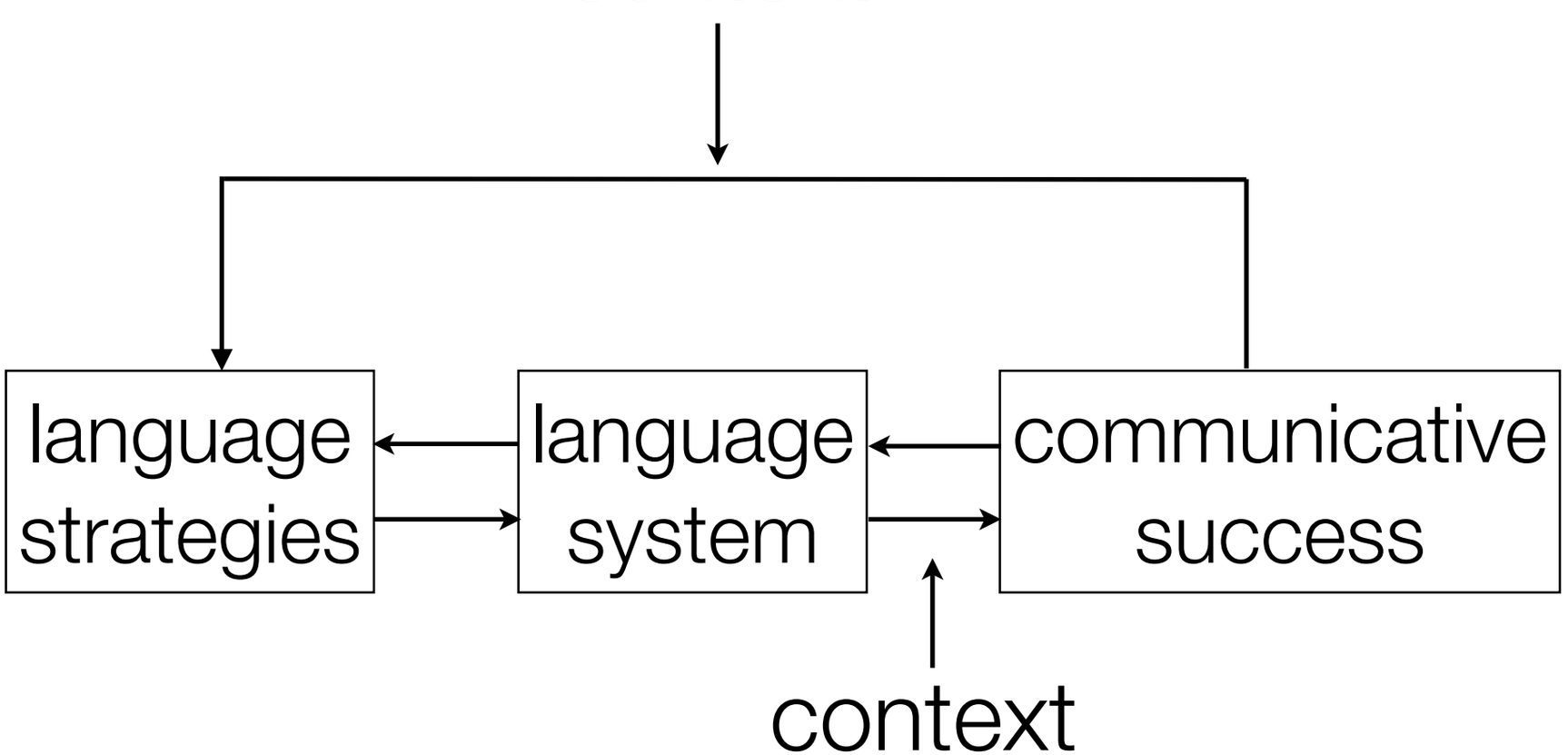
Bleys, J. and Steels, L. (2009) Linguistic Selection of Language Strategies: A Case Study for Colour. Proceedings of ECAL09.

Linguistic Selection of Language Strategies

- higher expressive power
- shared in population
- lower cognitive effort

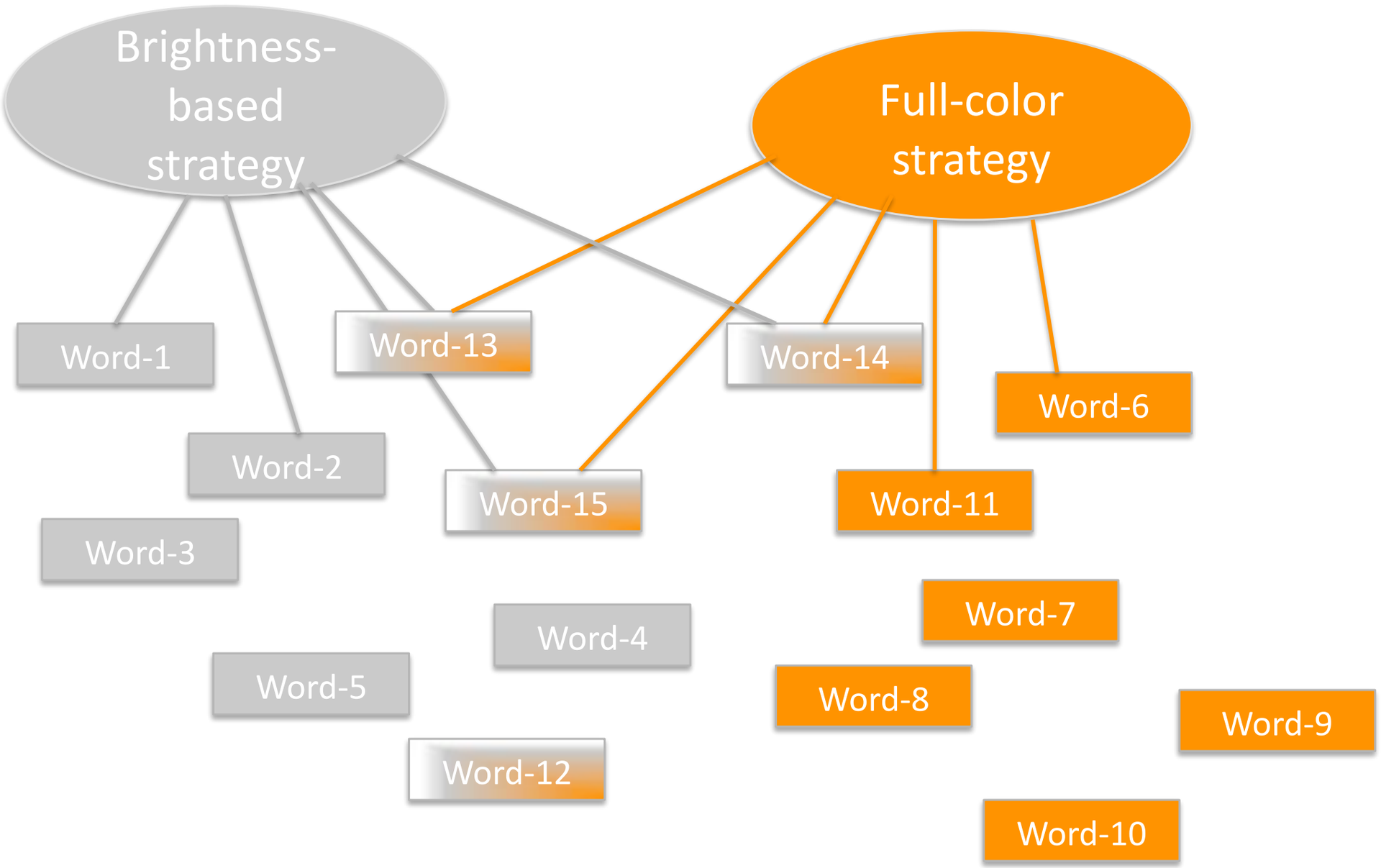
} selective advantage

context



Bleys, J. and Steels, L. (2009) Linguistic Selection of Language Strategies: A Case Study for Colour. Proceedings of ECAL09.
Steels, L. (2010) Can Evolutionary Linguistics Become a Science. *Journal of Evolutionary Linguistics*, 1. Submitted.

Linguistic Selection: implementation



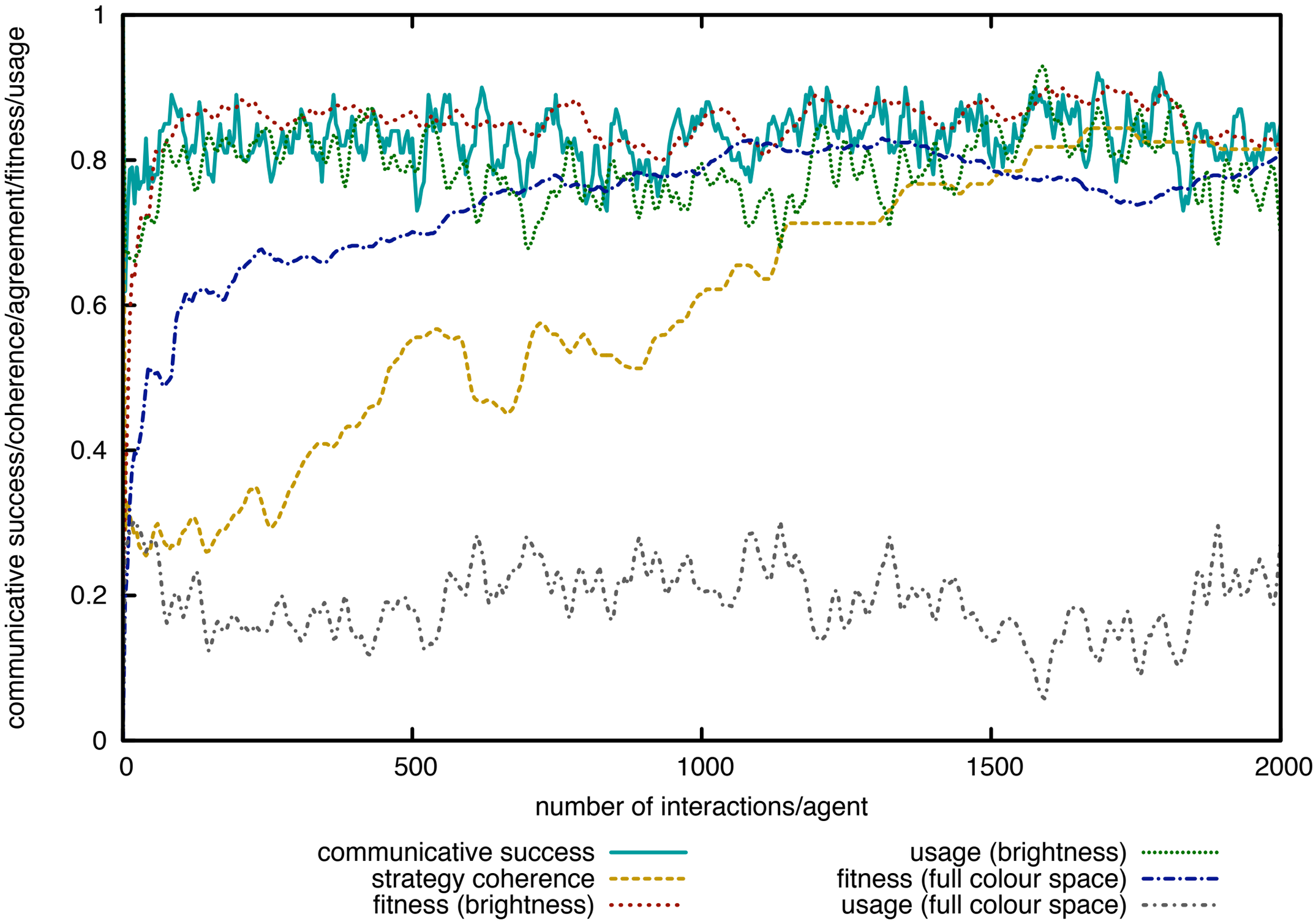
Bleys, J. and Steels, L. (2009) Linguistic Selection of Language Strategies: A Case Study for Colour. Proceedings of ECAL09.

Linguistic Selection: implementation

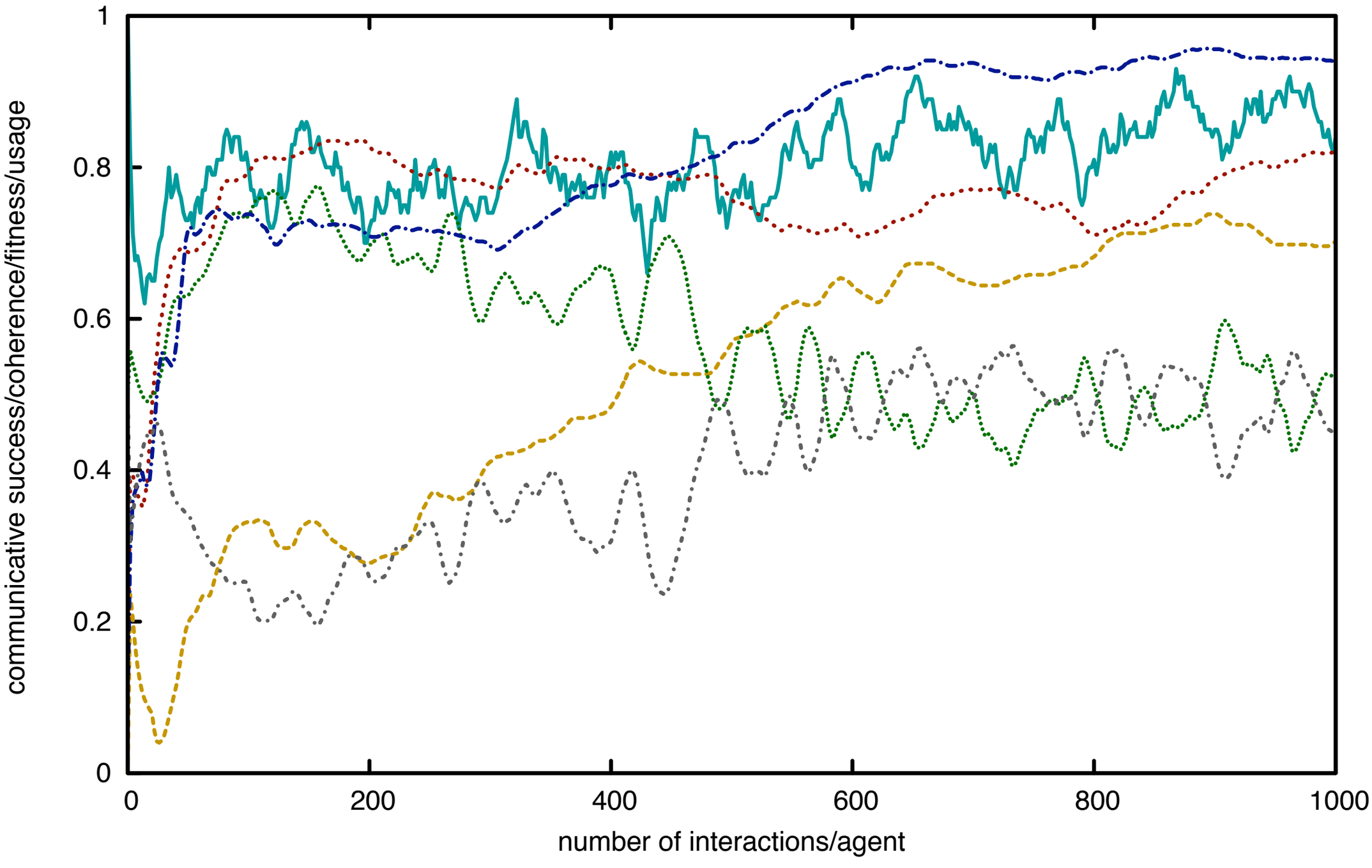
- production/interpretation
    - strategy preferred by linguistic item
    - otherwise re-interpretation using strategies sorted based on their fitness
- alignment
    - use strategy that was used during production/interpretation
- adoption/expansion
    - use strategy that is most fit and that is sufficient for current context

Bleys, J. and Steels, L. (2009) Linguistic Selection of Language Strategies: A Case Study for Colour. Proceedings of ECAL09.

Linguistic Selection: one strategy prevails



Linguistic Selection: co-existence of strategies



Current work: combination of strategies

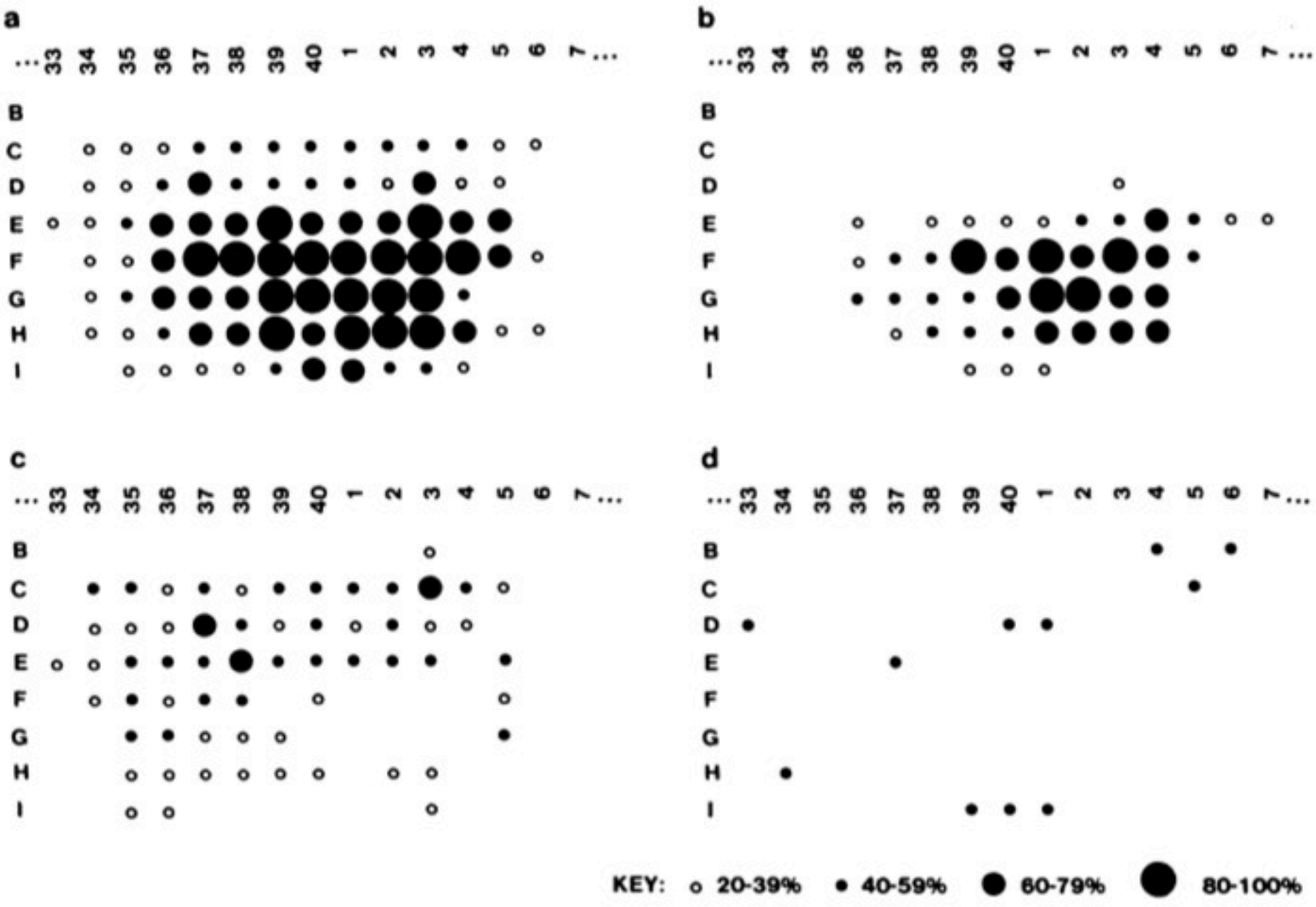


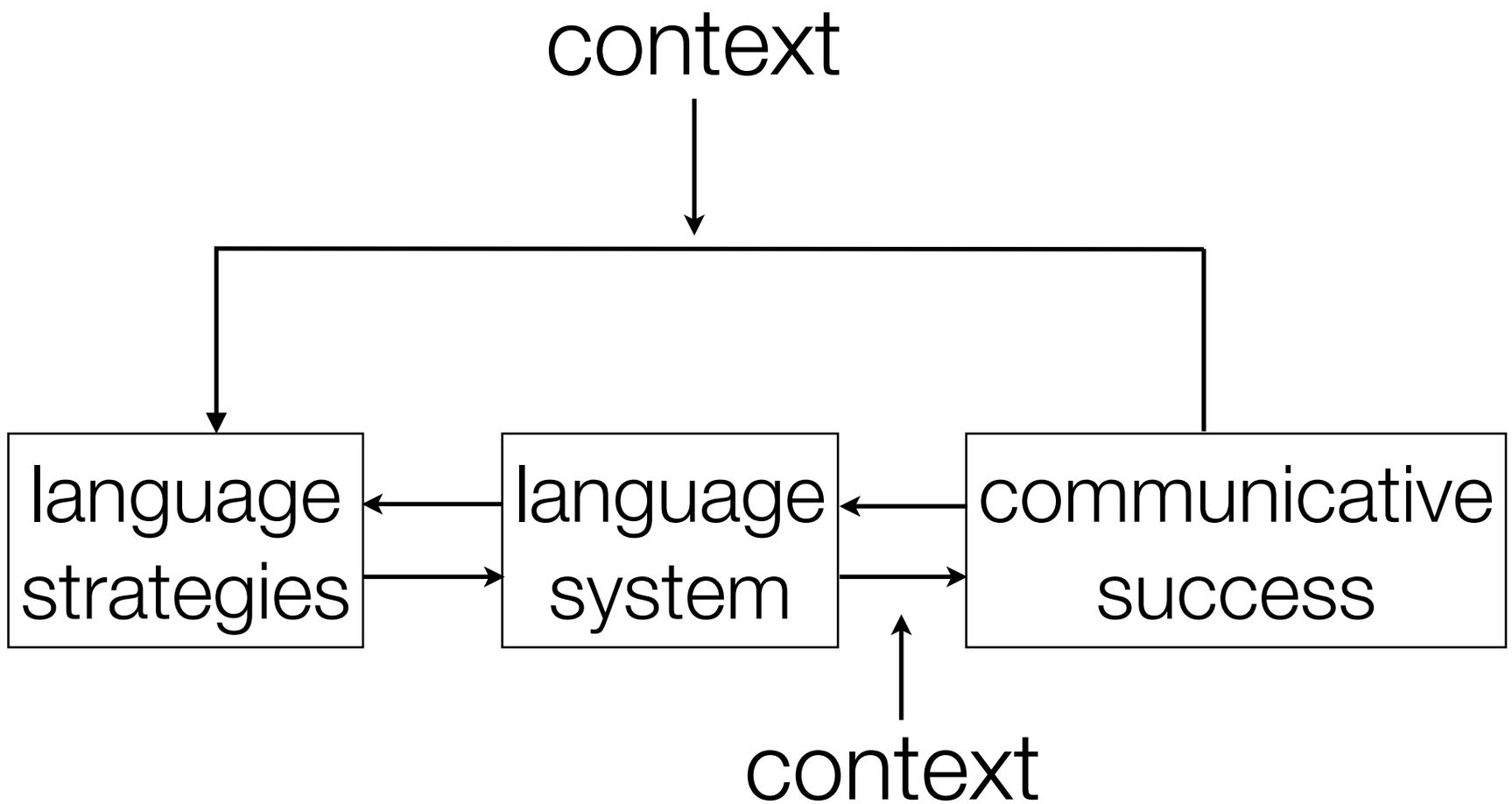
Figure 2. Aggregate data on *sitá-*, the red-focused category. Columns are rearranged from Figure 1, and the irrelevant columns 8 through 32 are deleted. (a) The root *sitá-*, combining all modifiers, aggregated from all 15 informants. (b) *Sitákame* (very red), aggregated from 9 informants. (c) *Sitáname* (somewhat red), aggregated from 9 informants. (d) *Sitánanti* (only slightly red), aggregated from 2 informants.

Burgress, D., Kempton, W. and Maclaury, R. (1983) Tarahumara color modifiers *American Ethnologist* (10), 133-149

Conclusion

- language strategies provide a methodology to study certain observations in the evolution of language

- coordination of language strategies can be orchestrated by communicative success



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- Steels, L. (2010) Can Evolutionary Linguistics Become a Science? *Journal of Evolutionary Linguistics* 1(1). Submitted.

Argument Structure

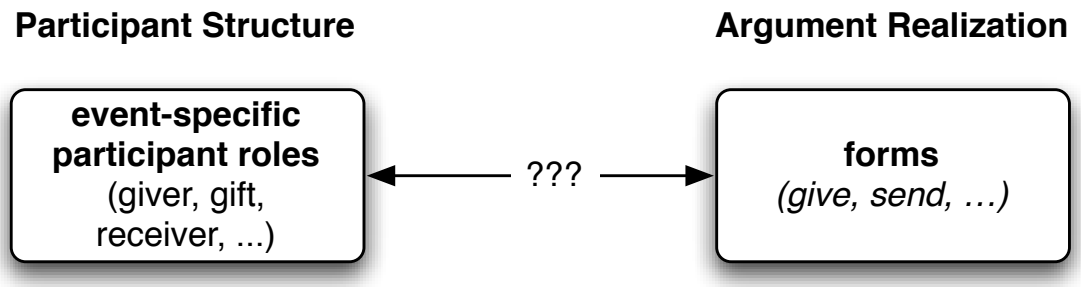
English

Argument Structure

Riau Indonesian (David Gil, pers. comm.)

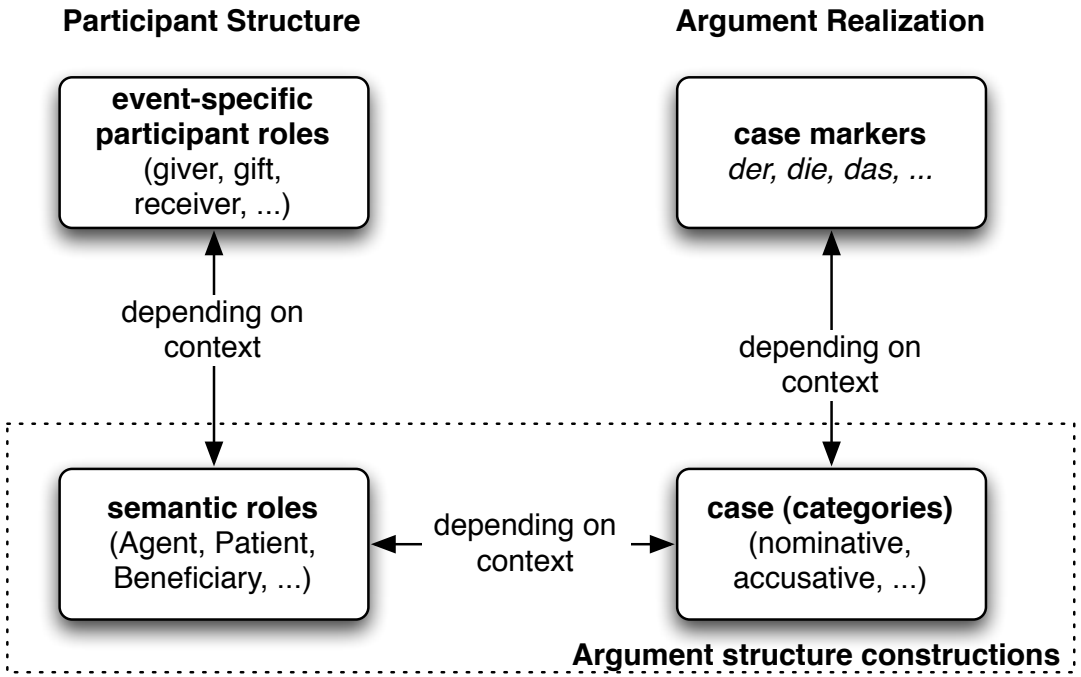
The emergence of case and argument structure

- FCG needs to be capable to handle language systems that go from:



The emergence of case and argument structure

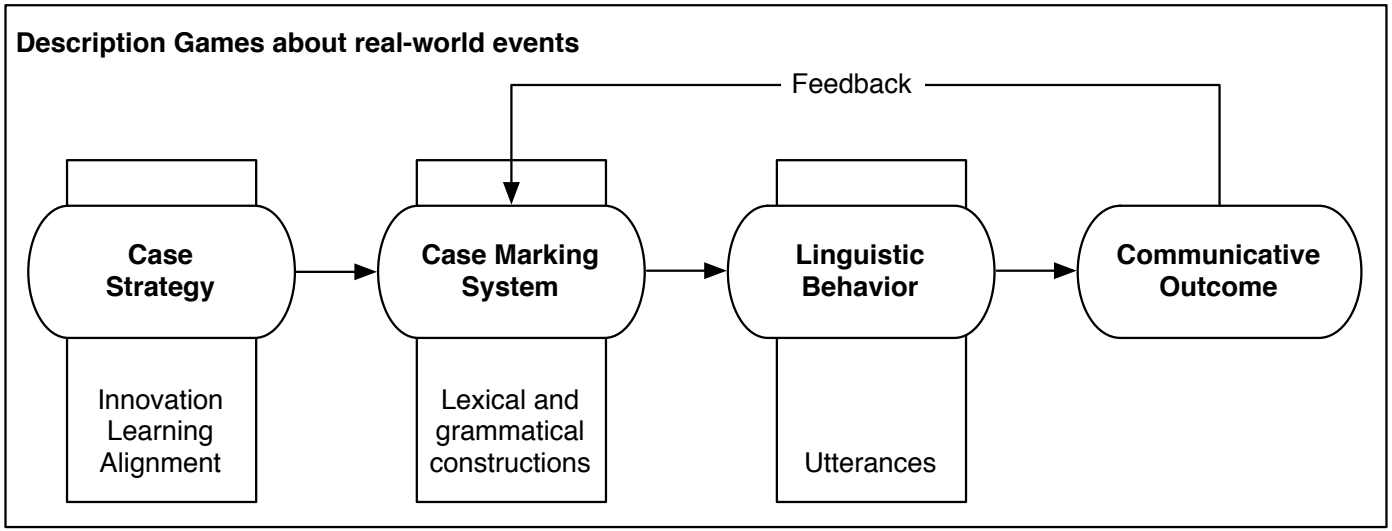
- To:



The emergence of case and argument structure

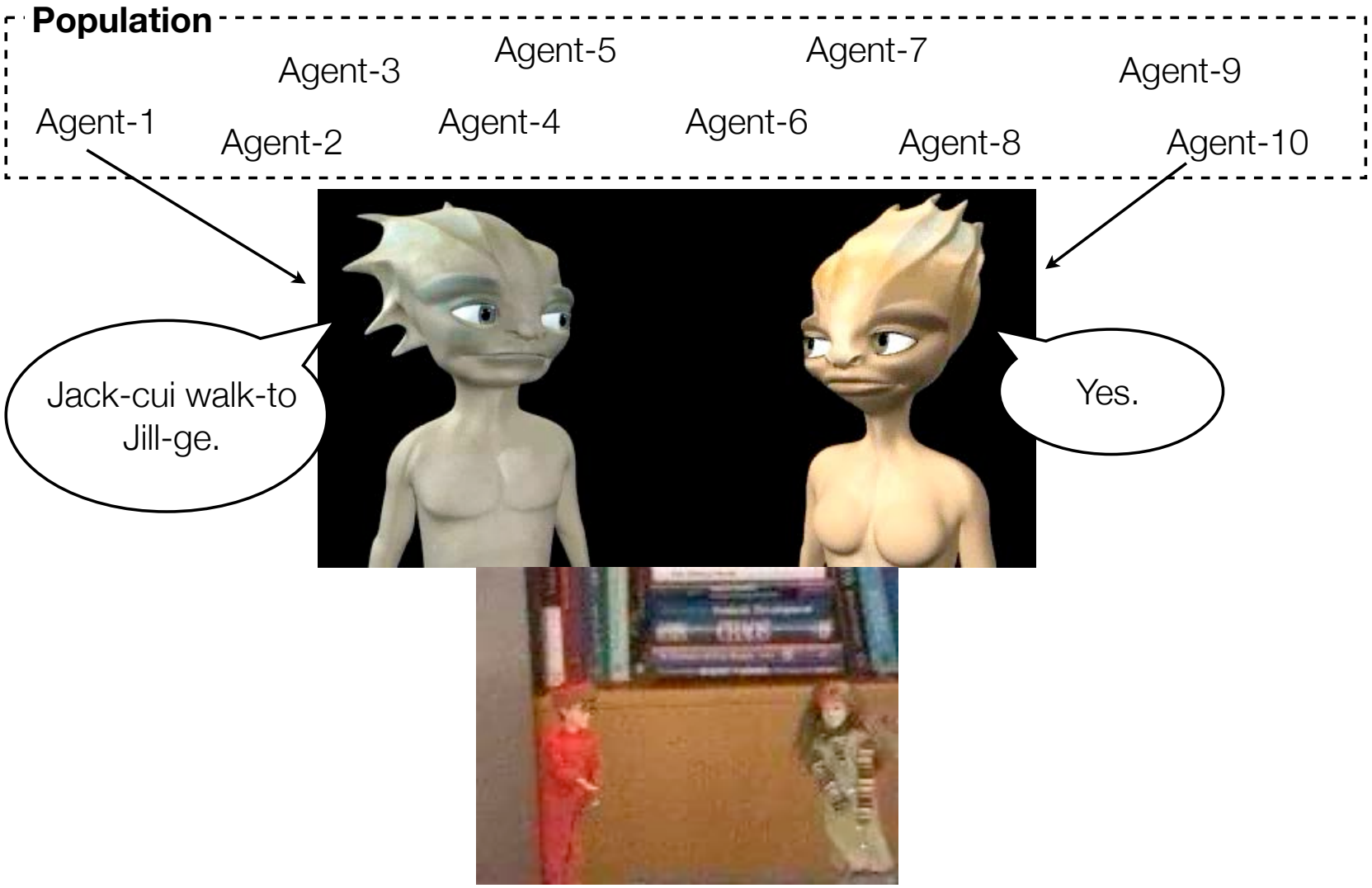
- Without predefined semantic or syntactic categories...
- With massive variation in the speech community...
- With great uncertainty about meaning/ function
- With various degrees of entrenchment
- ...

The Case Experiments



An artificial language

An artificial language



An artificial language

- *Jack-cui* *walk-to* *Jill-ge*

  jack-sem-role-6 walk-to Jill-sem-role-26
  'Jack walks to Jill.'

- *house-lu* *move-inside* *boy-cui*

  house-sem-role-10 move-inside boy-sem-role-6
  'The boy moves inside the house.'

Case marking for event structure

world model

(boy jack)
(girl jill)
(walk-to ev-1)
(walk-to-1 ev-1 jack)
(walk-to-2 ev-1 jill)

boy-**cui**

(boy ?puppet-x)

?puppet-x = ?walker

walk-to

(walk-to ?ev)
(walk-to-1 ?ev ?puppet-x)
(walk-to-2 ?ev ?puppet-y)

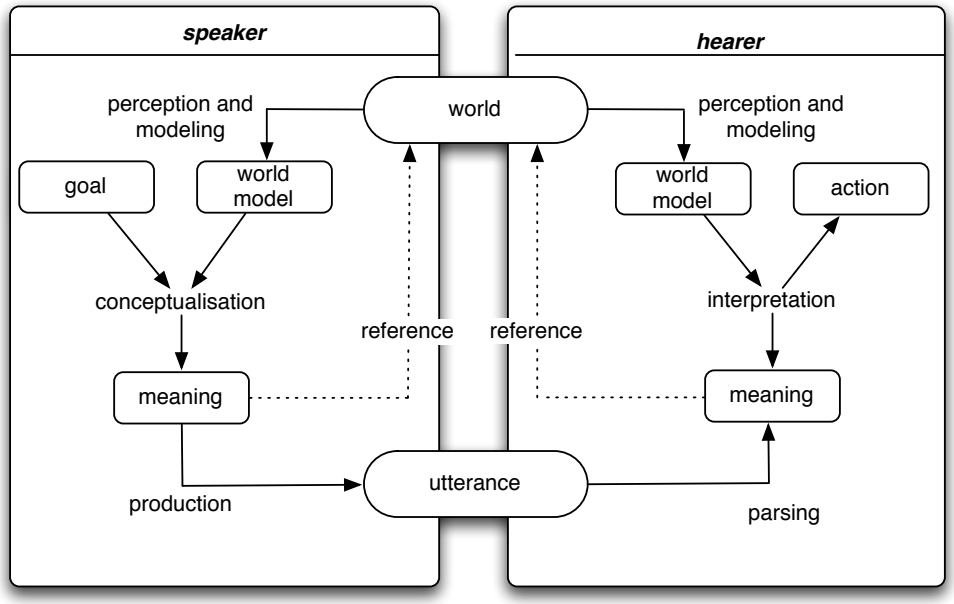
girl-**ge**

(girl ?puppet-y)

?puppet-y = ?walked-to

Experimental set-up

- Population of agents
- Given lexicon, but no grammar
- Play description games
- Problem-solving approach:
  - Diagnostics
  - Repair strategies
  - Consolidation strategies

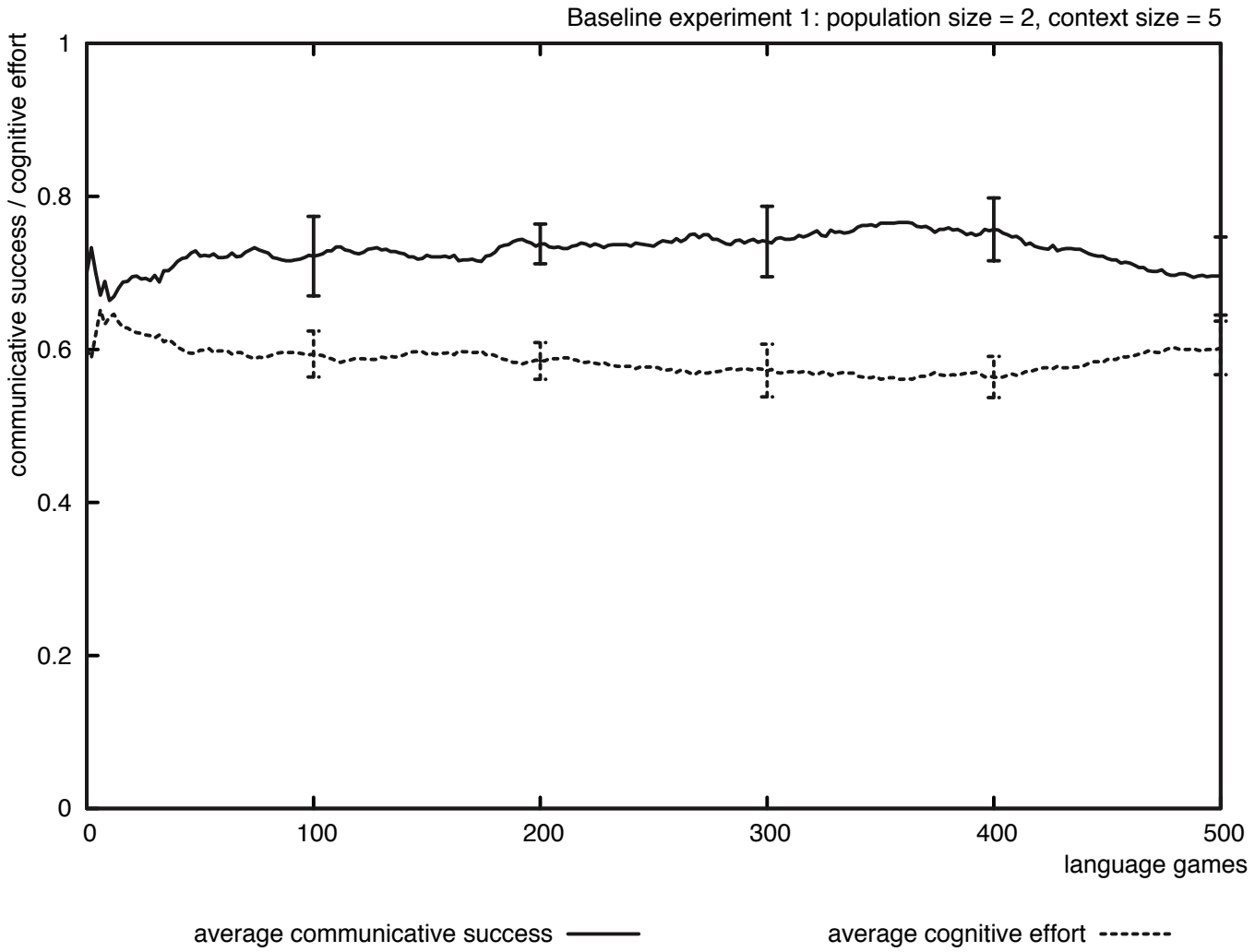


Comparative experiments

Diagnostics and repairs

		Detecting and resolving variable equalities	Invention and adoption of new markers	Reuse and generalisation of existing markers
Stage 1	**Baseline experiment 1**	+	-	-
Stage 2	**Baseline experiment 2**	+	+	-
Stage 3	**Baseline experiment 3**	+	+	+

Baseline: a lexical language



No marking in natural languages

- Riau Indonesian
  - *ayam* *makan*
    chicken eat
- English
  - *the shooting of the hunters*

Baseline: a lexical language

- Why would grammar be useful for communication?
  - reducing cognitive effort
  - avoiding ambiguity
  - increasing expressiveness (generalization)

The experiments: stage 2

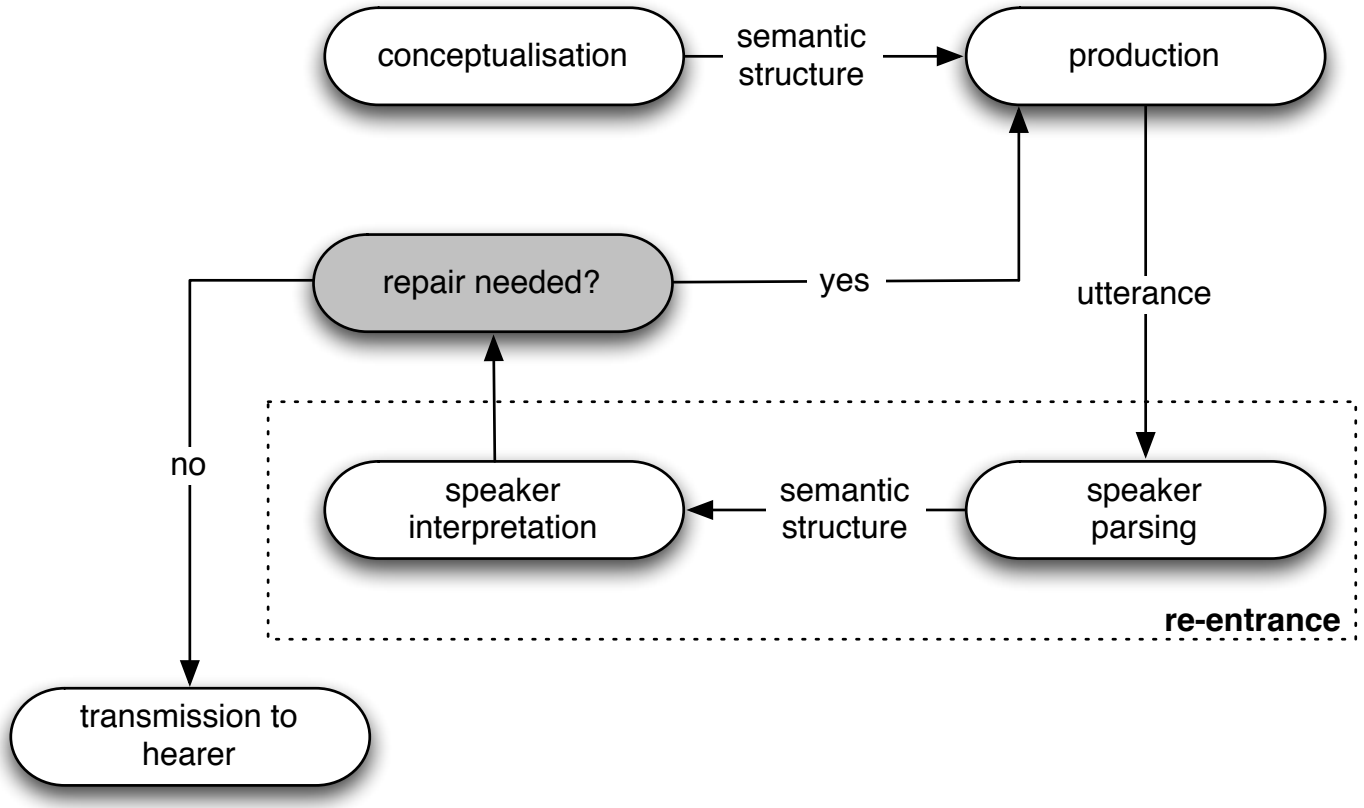
- Stage 2: specific marking

  - **diagnostic:** re-entrance for diagnosing cognitive effort and ambiguity
    > “boy walk”
    > cognitive effort needed

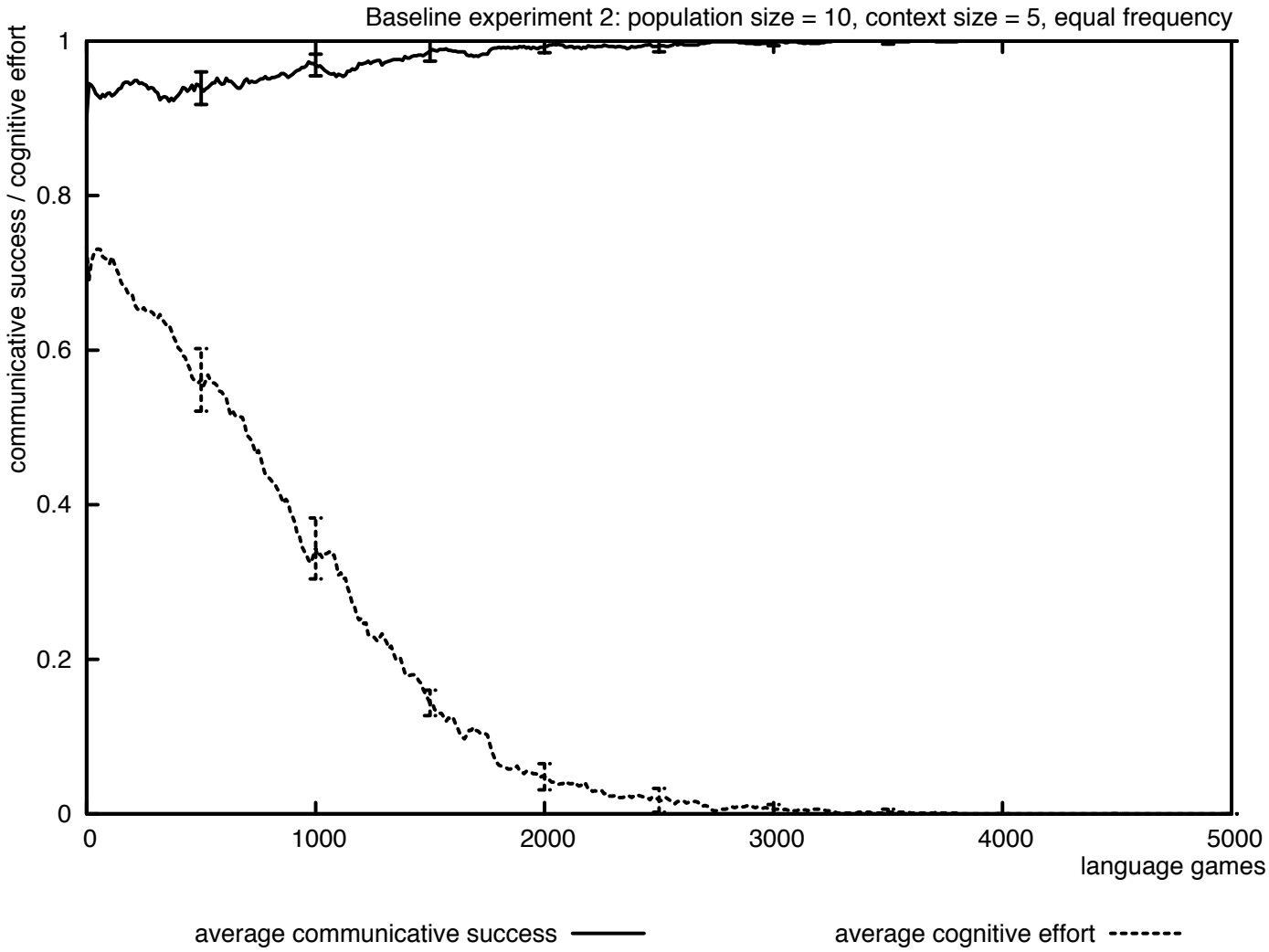
  - **repair strategy:** invention and adoption strategy
    > “boy -bo walk”

  - **alignment strategy**: lateral inhibition
    > walk-to-1 <--0.6--> “-bo”
    > walk-to-1 <--0.4--> “-ka”

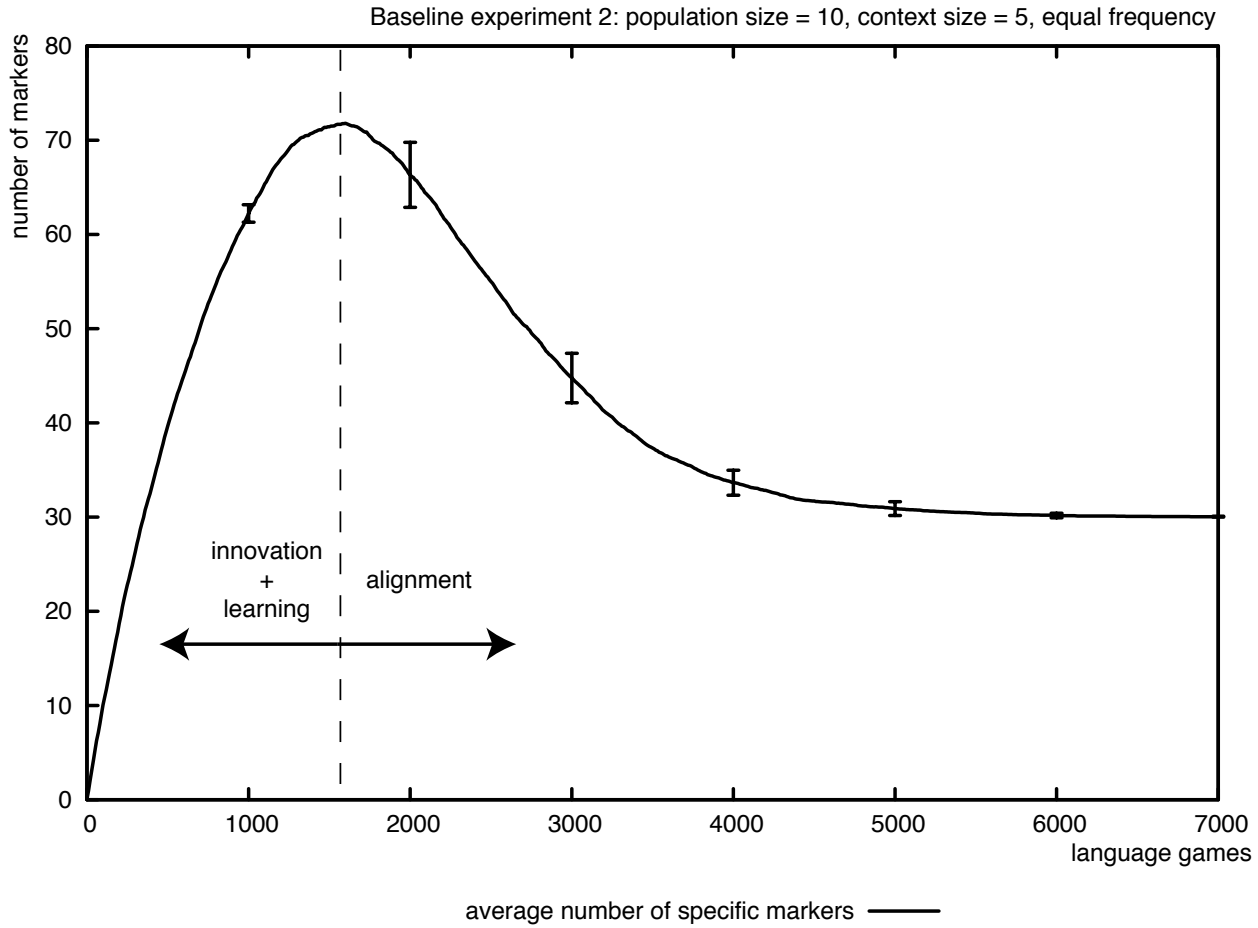
The experiments: stage 2



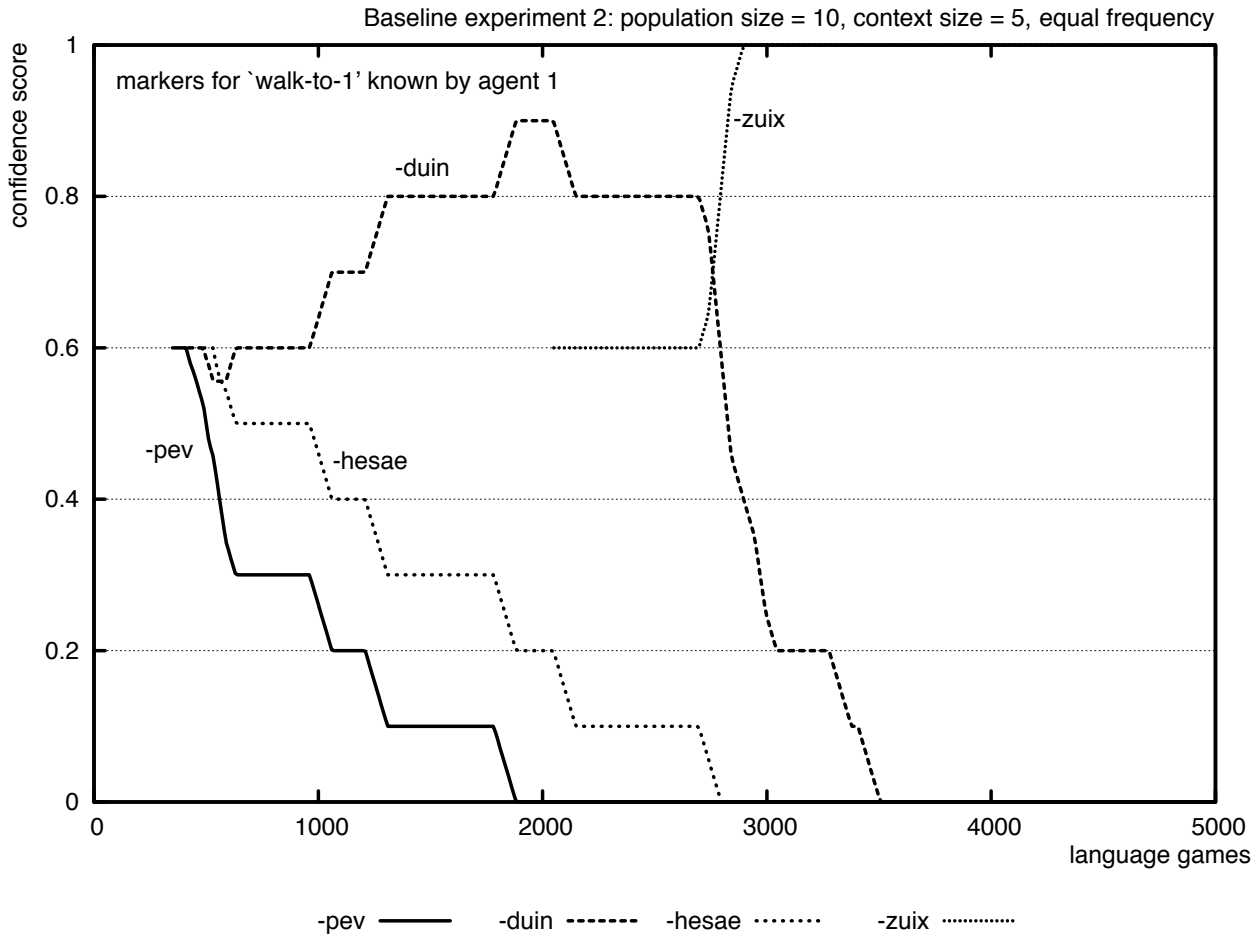
The experiments: stage 2



The experiments: stage 2



The experiments: stage 2



The experiments: stage 2

- Stage 2: specific marking in natural languages
  - *thân* *cà* *bin* *maakrungthêep* (Thai)
    he will fly come Tokyo
    “He will fly to Tokyo.”
  - A man comes pulling a goat.

The experiments: stage 2

- Why isn't this strategy enough?
  - no generalization
  - explosion of inventory size

The experiments: stage 3

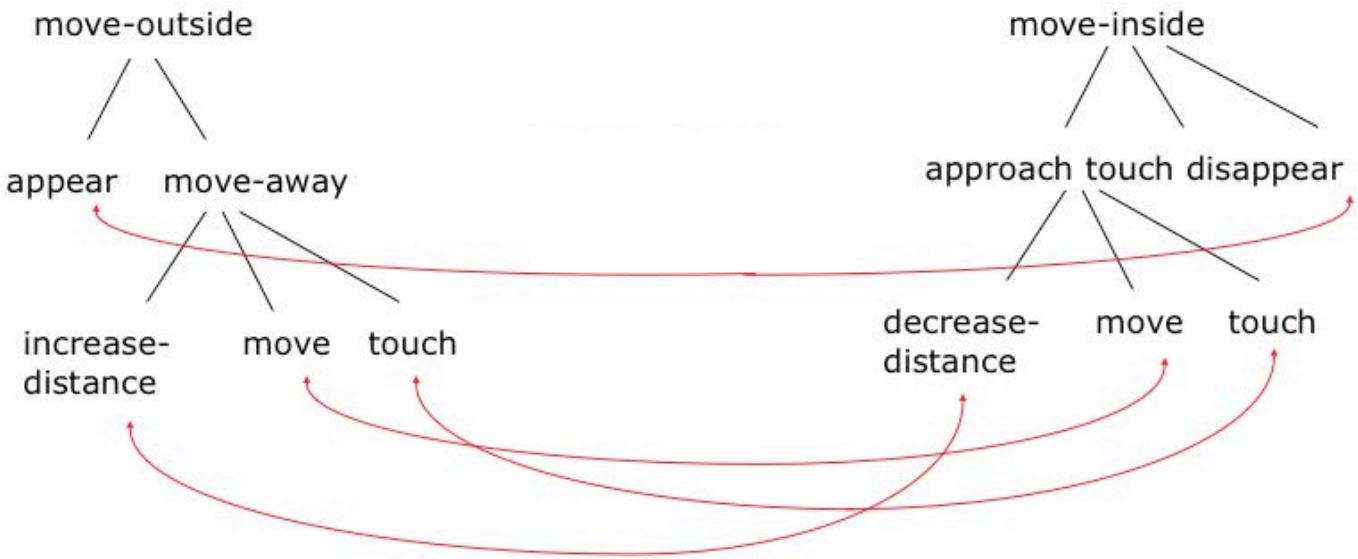
- Stage 3: extension through analogy

  - **diagnostic:** re-entrance for diagnosing cognitive effort
    > “boy walk”
    > cognitive effort needed

  - **repair strategy:** try to reuse existing marker, else invent or adopt a new one
    > “boy -bo walk”
    > “boy -bo move”

  - **alignment strategy**: lateral inhibition
    > walk-to-1 <--0.6--> “-bo”
    > walk-to-1 <--0.4--> “-ka”

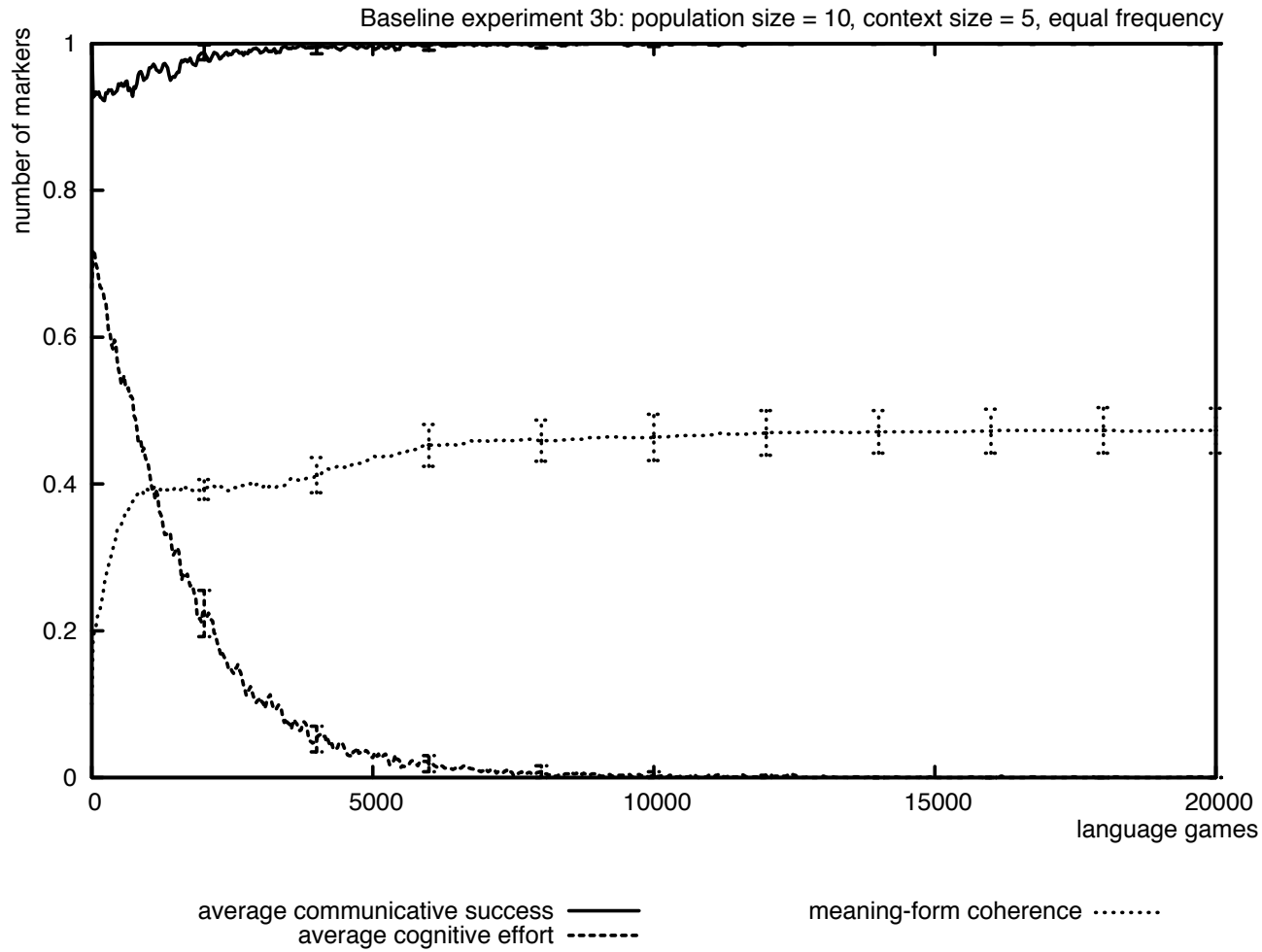
The experiments: stage 3



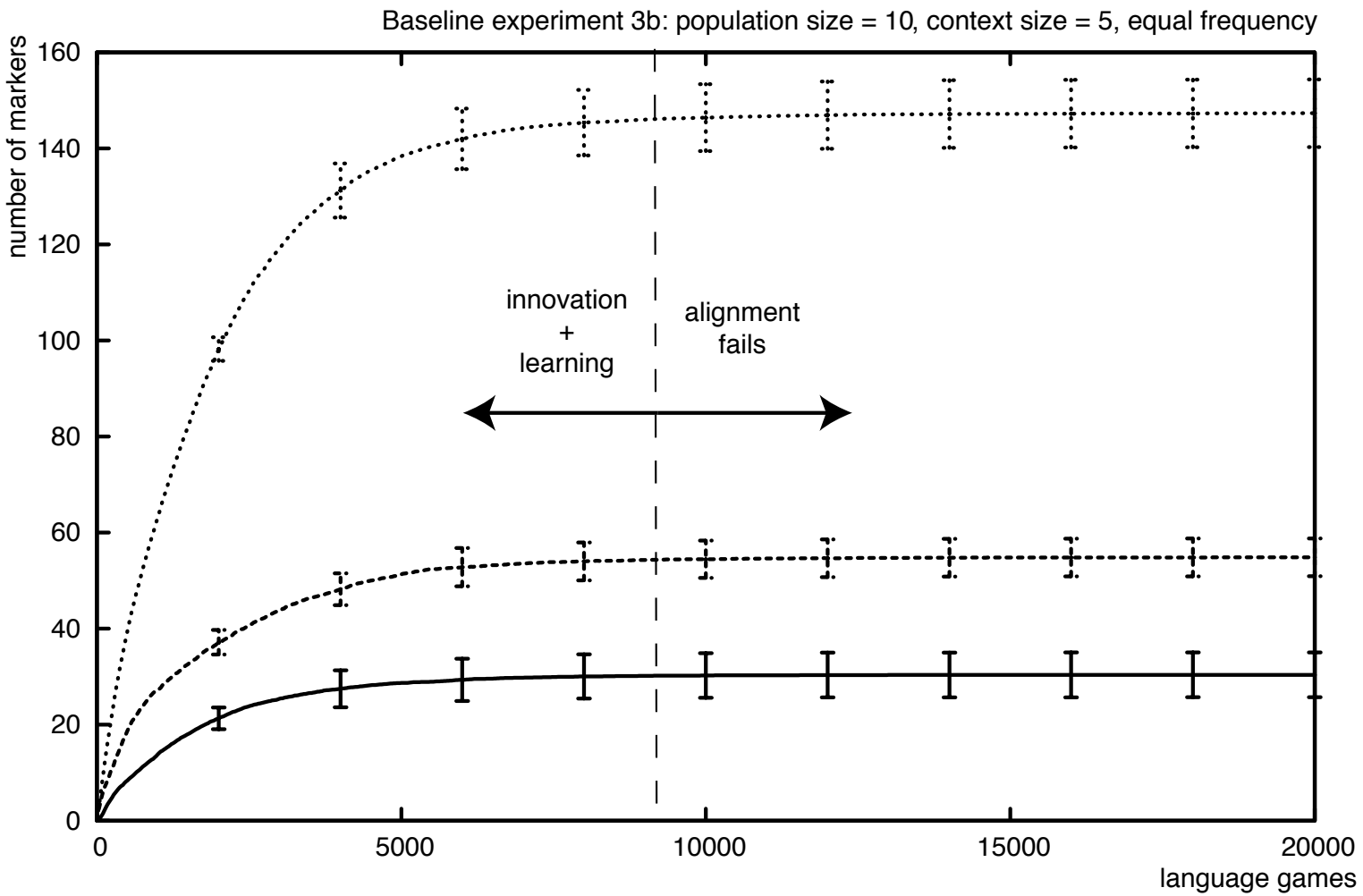
The experiments: stage 3

- Analogy
  - First try to find an existing and analogous marker
  - Always try markers with highest **type frequency** first
  - If no analogy could be found, invent an existing marker

The experiments: stage 3



The experiments: stage 3

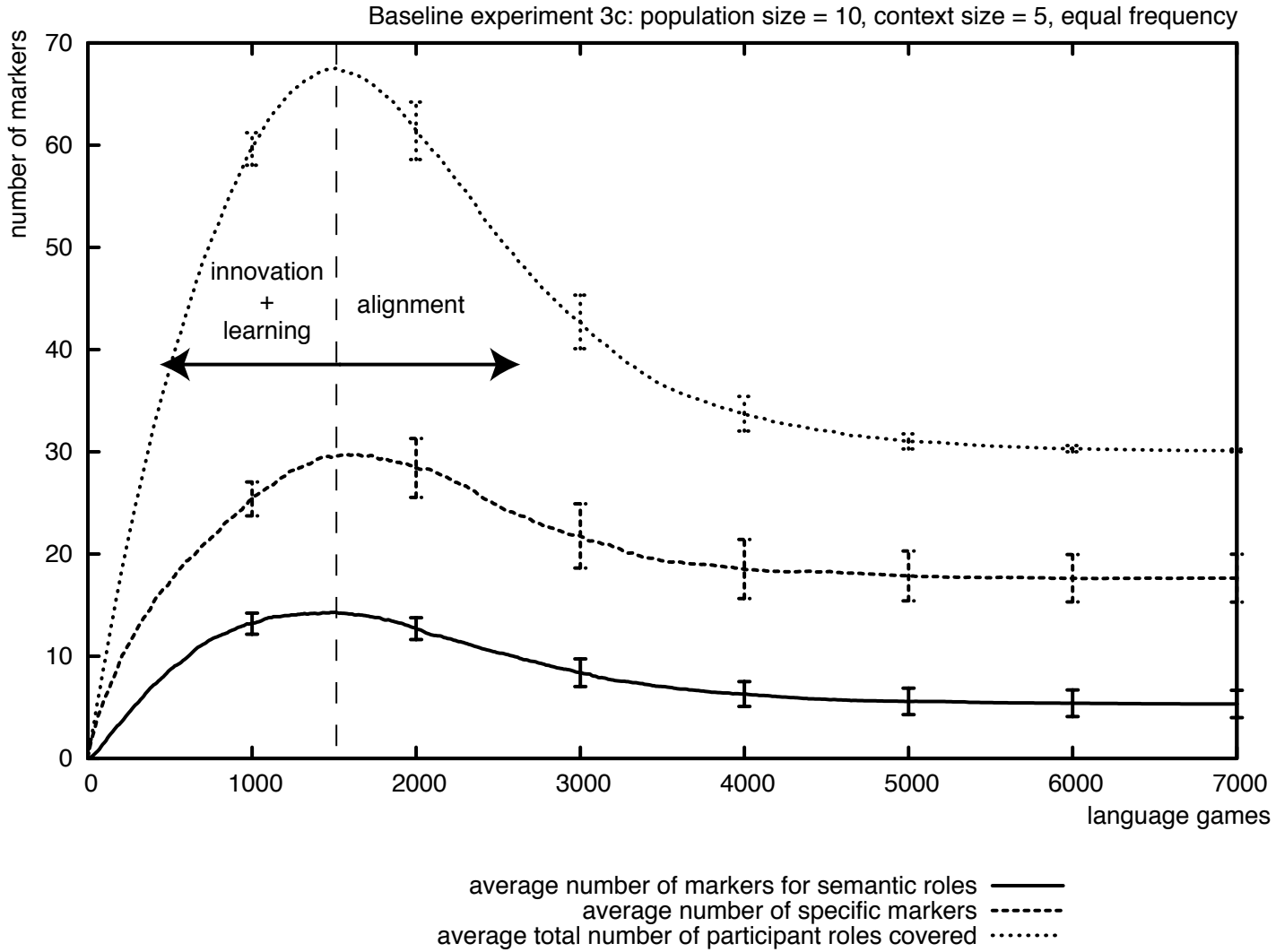


The experiments: stage 3

- Why does it fail?
  - **polysemy:** many-to-one mappings of semantic roles
  - move-1 <-0.6-> -bo
    move-inside-1

    move-inside-1 <-0.5-> -ka
    move-outside-1
  - The alignment strategy is not fine-grained enough!

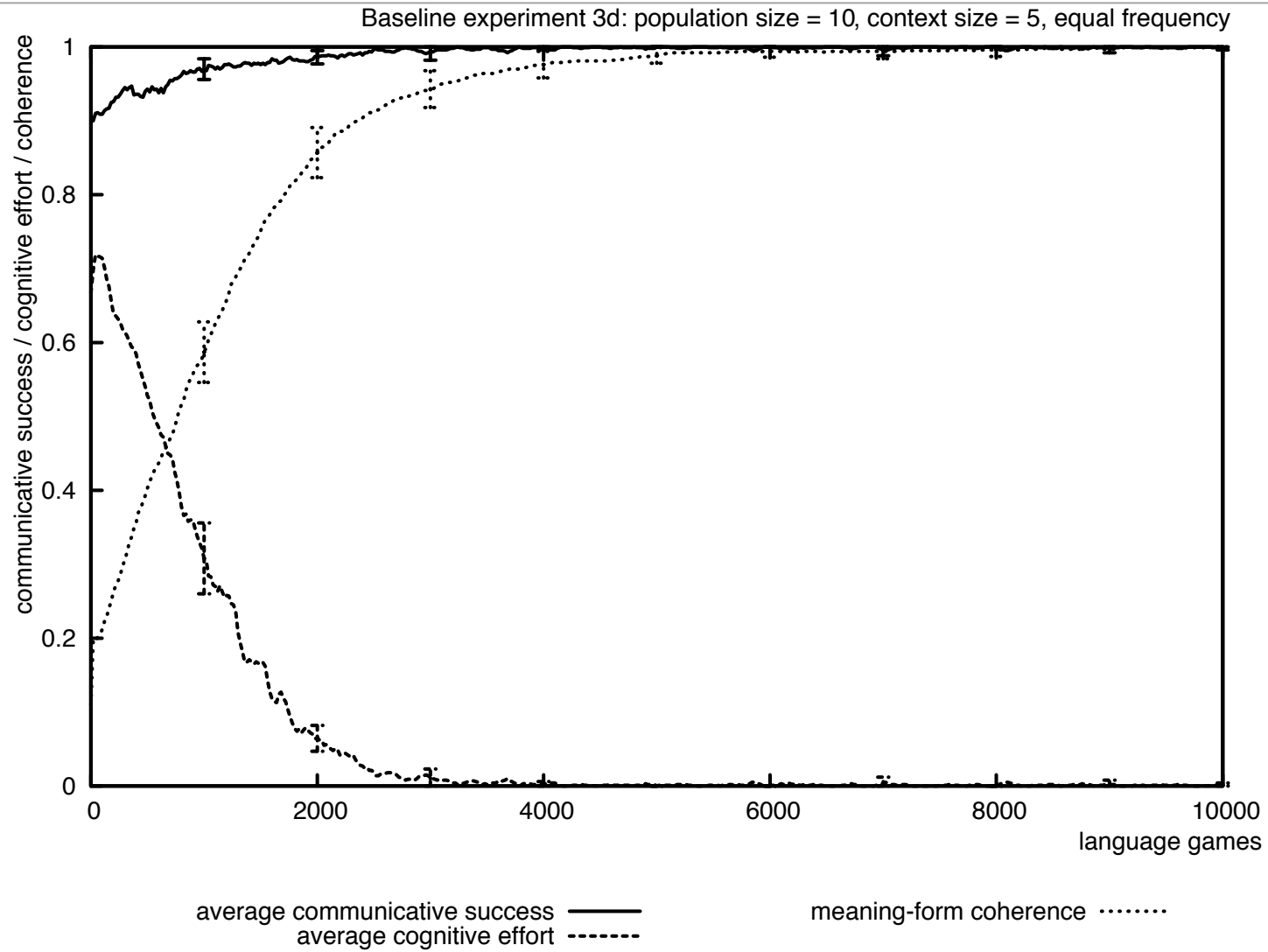
The experiments: stage 3



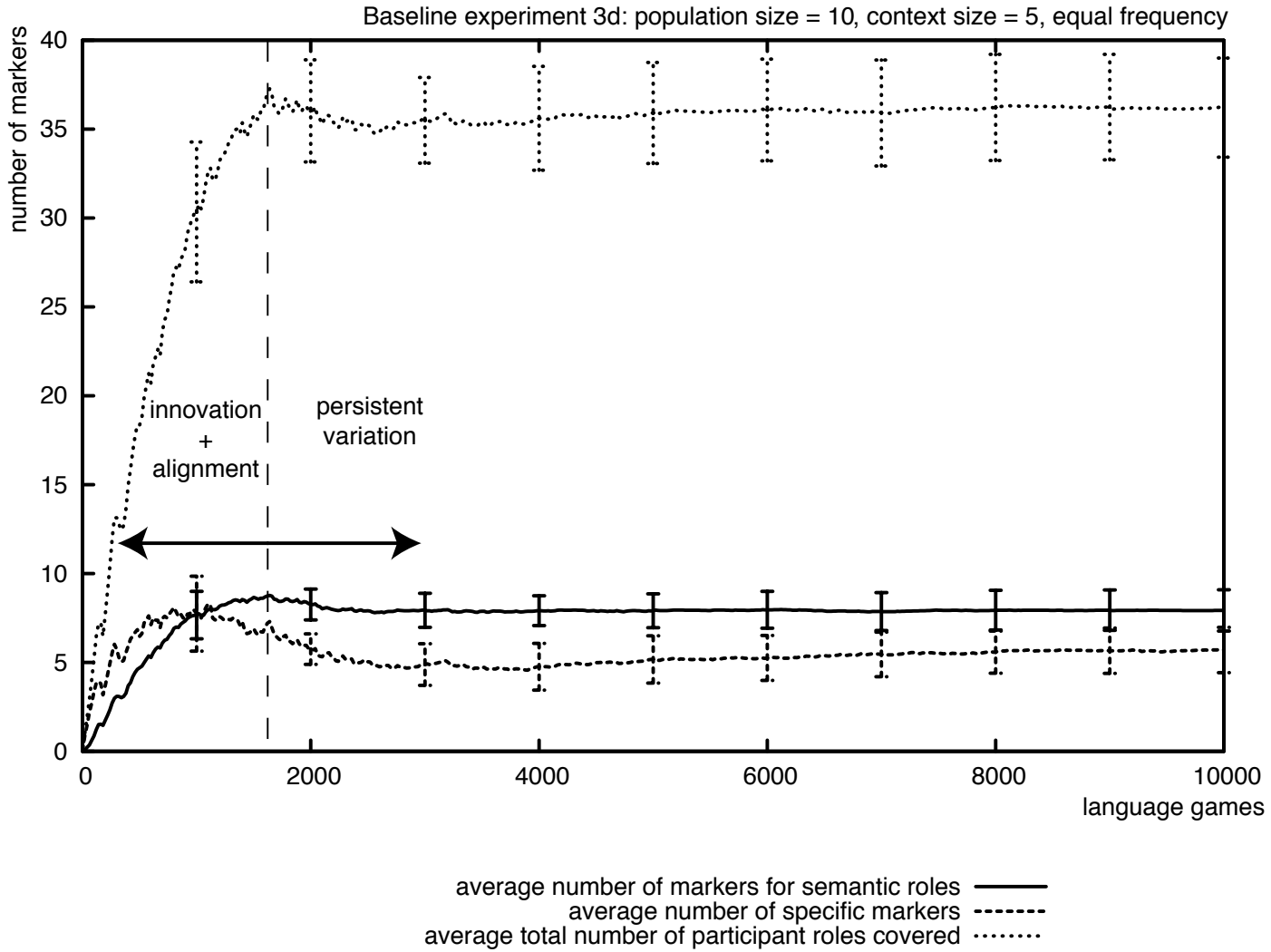
The experiments: stage 3

- Convergence: yes, but (almost) no generalization
  - Fine-grained strategy does not prefer more general roles
  - Each new role has to be negotiated as if it were a new lexical item
  - New strategy:
    - token frequency during processing
    - type frequency during semantic extension

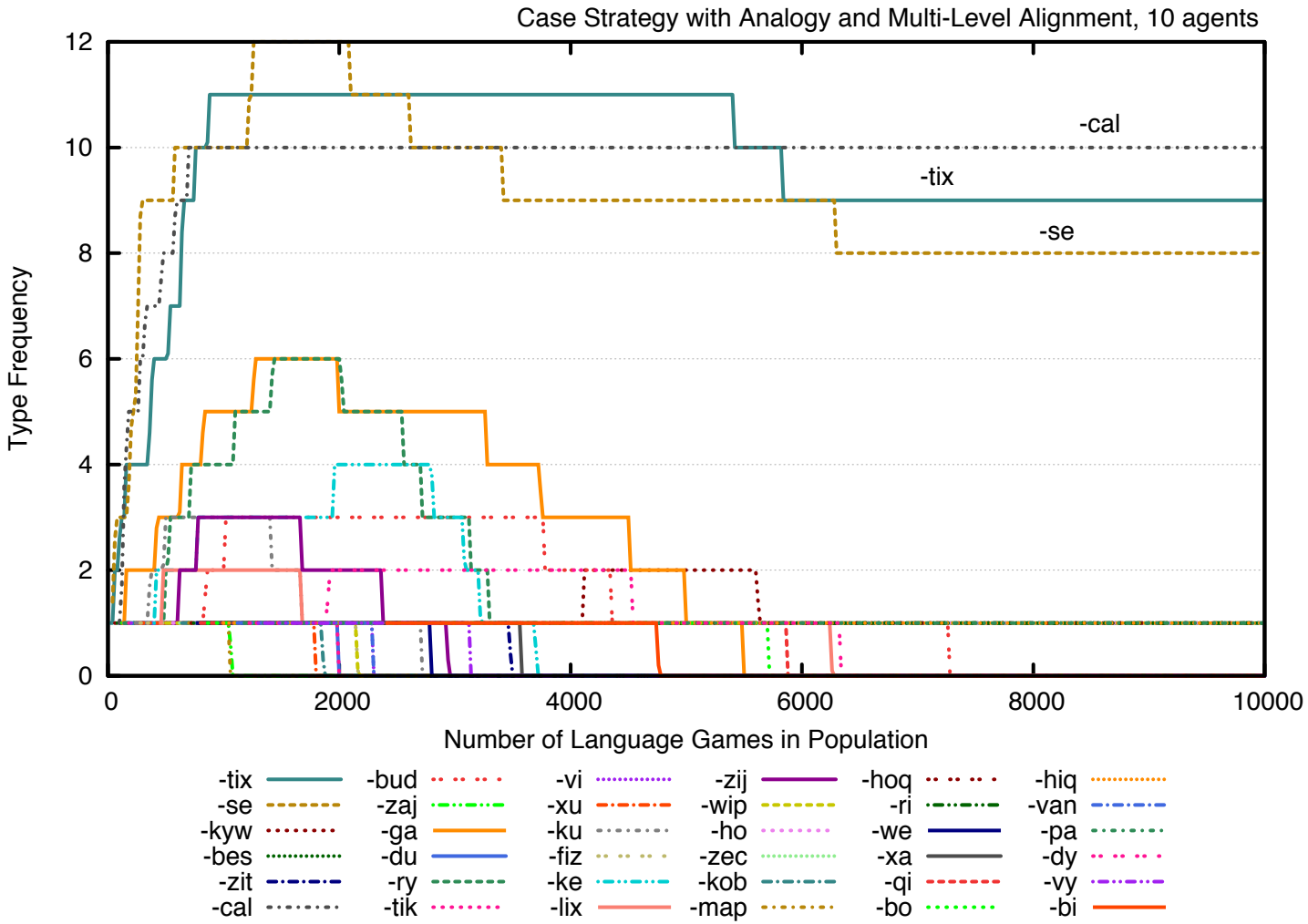
The experiments: stage 3



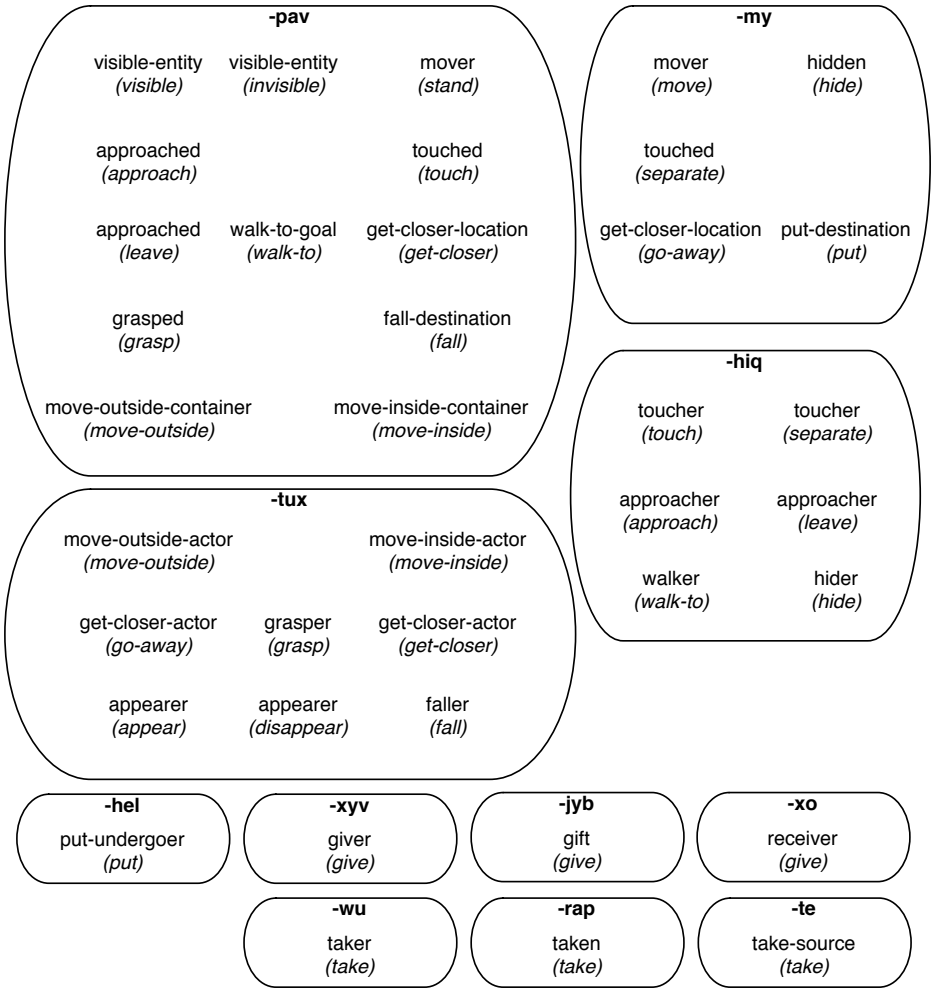
The experiments: stage 3



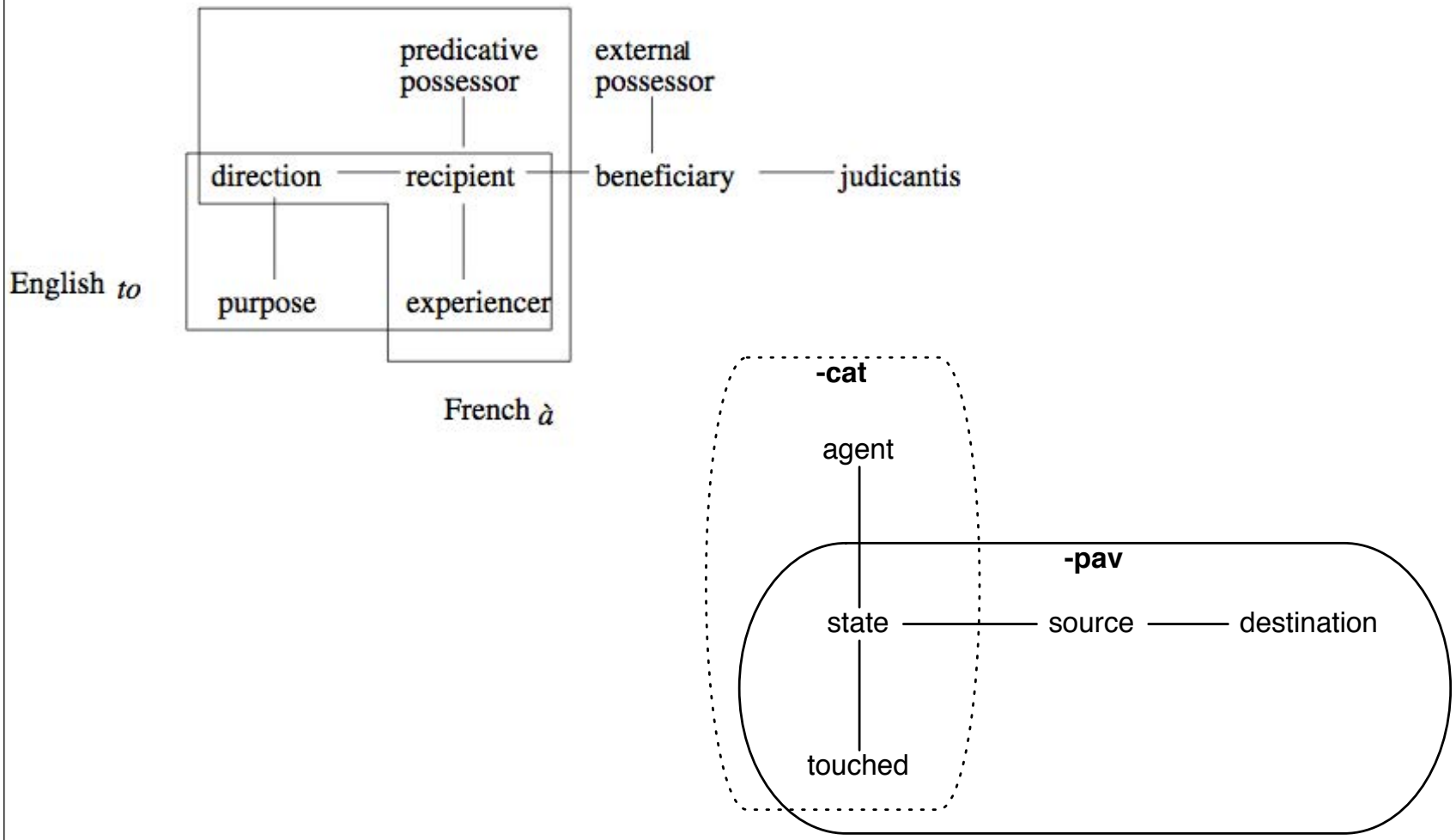
The experiments: stage 3



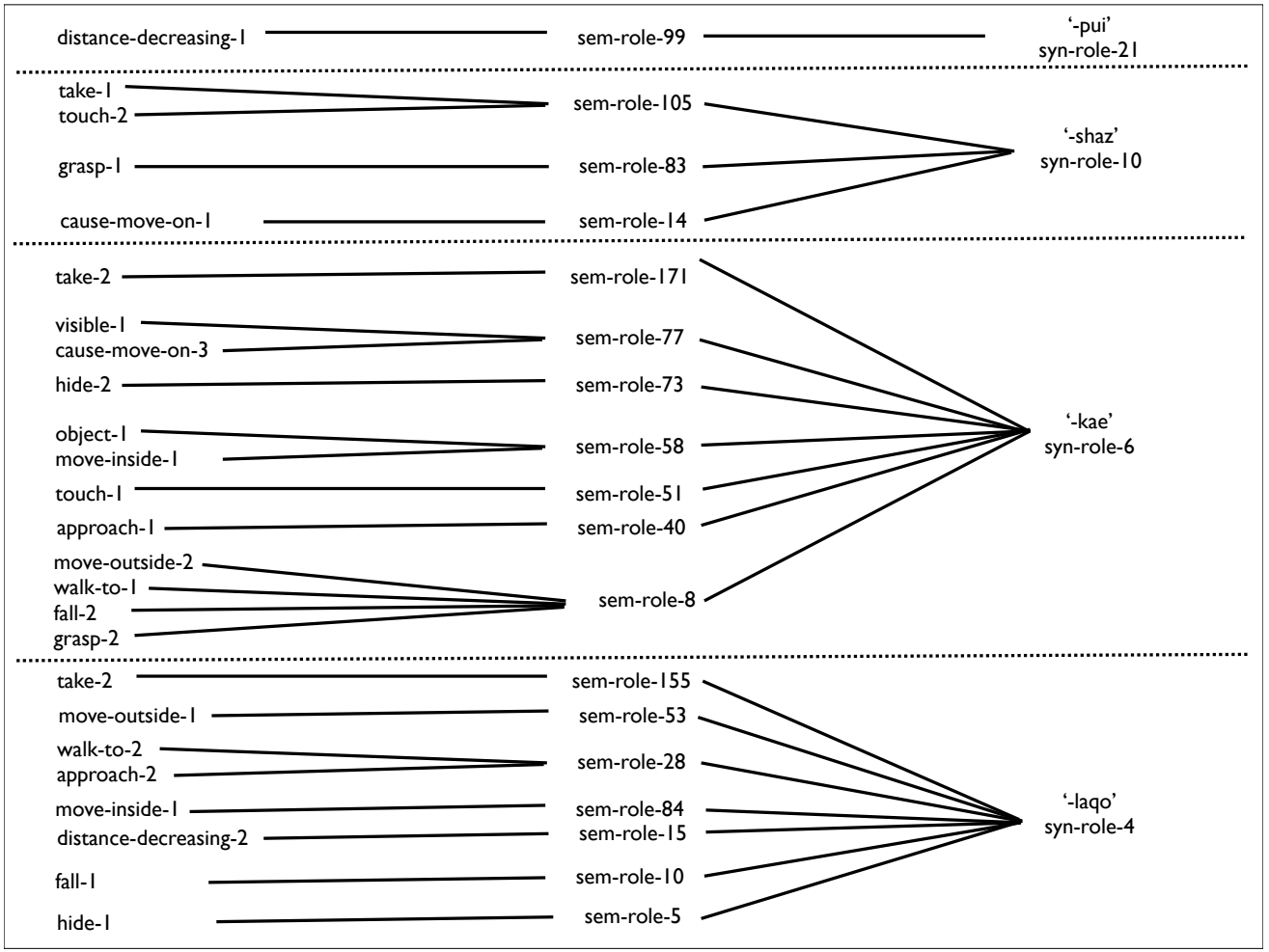
The experiments: stage 3



The experiments: stage 3



The experiments: stage 3



The experiments: stage 3

- *jack -fuitap walk-to jill -ginah*
  Jack sem-role-7 walk-to Jill sem-role-24
  'Jack walks to Jill.'

- *touch jill -fuitap house -payis*
  touch Jill sem-role-7 house sem-role-29
  'Jill touches the house.'

- *house -woechen move-inside boy -fuitap*
  house sem-role-56 move-inside boy sem-role-7
  'The boy moves inside the house.'

Example IV
Explaining Real Language Change

- van Trijp, Remi (2012). "The Evolution of Case Systems for Marking Event Structure."
- van Trijp, Remi (2012). "Self-Assessing Agents for Explaining Language Change."

German definite articles

Case	SG-M	SG-F	SG-N	PL-M	PL-F	PL-N
Nom	*dër*	*diu*	*daz*	*die*	*deo*	*diu*
Acc	*dën*	*die*	*daz*	*die*	*deo*	*diu*
Dat	*dëmu*	*dëru*	*dëmu*	*dēm*	*dēm*	*dēm*
Gen	*dës*	*dëra*	*dës*	*dëro*	*dëro*	*dëro*

Old High German demonstratives (900-1100 AD; Wright 1906)

German definite articles

Case	SG-M	SG-F	SG-N	PL-M	PL-F	PL-N
Nom	dër	diu	daz	die	diu	die
Acc	dën	die	daz	die	diu	die
Dat	dëm	dër	dëm	dēn	den	dēn
Gen	dës	dër	dës	dër	dër	dër

Middle High German definite articles (1100-1500 AD; Wright 1916)

German definite articles

Case	SG-M	SG-F	SG-N	PL
Nom	*der*	*die*	*das*	*die*
Acc	*den*	*die*	*das*	*die*
Dat	*dem*	*der*	*dem*	*den*
Gen	*des*	*der*	*des*	*der*

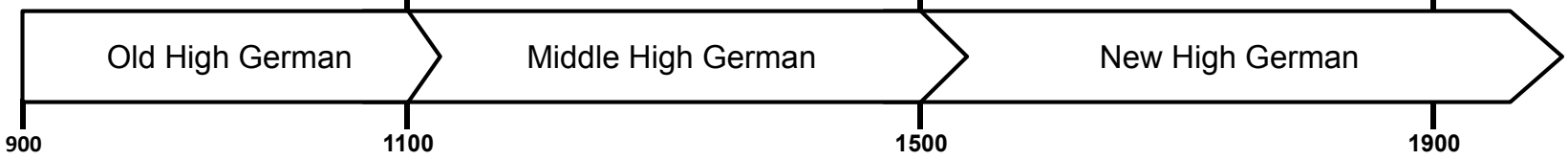
New High German definite articles

German definite articles

	Masc	Neut	Fem
	Singular		
NOM	*dër*	*daz*	*diu*
ACC	*dën*	*daz*	*die*
DAT	*dëmu*	*dëmu*	*dëru*
GEN	*dës*	*dës*	*dëru*
	Plural		
NOM	*die*	*diu*	*deo*
ACC	*die*	*diu*	*deo*
DAT	*dēn*	*dēn*	*dēn*
GEN	*dëro*	*dëro*	*dëro*

Masc	Neut	Fem
Singular		
dër	*daz*	*diu*
dën	*daz*	*die*
dëm	dëm	dër
dës	*dës*	*dër*
Plural		
die	*diu*	*die*
die	*diu*	*die*
dën	*dën*	*dën*
dër	*dër*	*dër*

Masc	Neut	Fem
Singular		
der	*das*	*die*
den	*das*	*die*
dem	*dem*	*der*
des	*des*	*der*
Plural		
die	*die*	*die*
die	*die*	*die*
den	*den*	*den*
der	*der*	*der*



900 1100 1500 1900

Why?

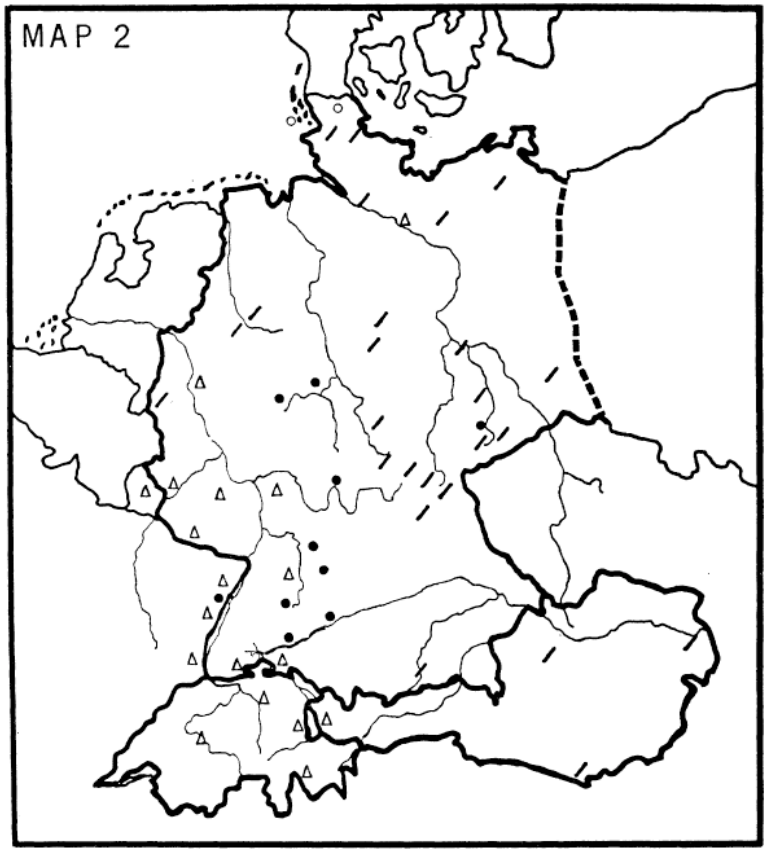
What do experts say?

- Formal perspective:
  Non-systematic (accidental) syncretism
- Historical perspective: historical accident

*"**Accidental** syncretism occurs as a by-product of phonological or morphological changes. For example, the collapse of case forms due to phonological reduction or loss is a familiar theme in the history of Indo-European languages, as in Middle High German, where the reduction of unstressed vowels in final syllables to schwa (graphically e) in Middle High German led to widespread mergers throughout the inflectional system"*
(Baerman 2009)

Problems for the accidental hypothesis

- The "accidental" paradigm has survived for several centuries despite huge structural variation & language contact
- "Explanations" only say *what* has happened, but not *why*



(Shrier 1965)

Case loss in Germanic

- Phonological erosion
- Change from synthetic to analytic
- Change from free to fixed word order
- Change from lexical to structural case
- Development of the definite article
- Merger of (partially synonymous) argument structure constructions & attraction by high type frequency constructions

(Barðdal 2009)

Evolutionary Linguistics

- Linguistic selectionism
  - Processes that cause variation
  - Selection of variants because of advantages for linguistic communication

Can we demonstrate the validity of our hypothesis?

"Old High German field work is no option."

True... But we can "bring back alive" Old High German!

(Fleischer 2012)

Research Plan

- Step 1: Bring back "alive" a language through a processing model

Implementation details of the grammar:

R. van Trijp (2011a). A Design Pattern for Argument Structure Constructions in Fluid Construction Grammar.

R. van Trijp (2011b). Feature Matrices and Agreement: A Case Study for German Case.

R. van Trijp (subm). Handling Structural Variation in Feature-Structure Grammars.

>> Online demo of the approach: www.fcg-net.org

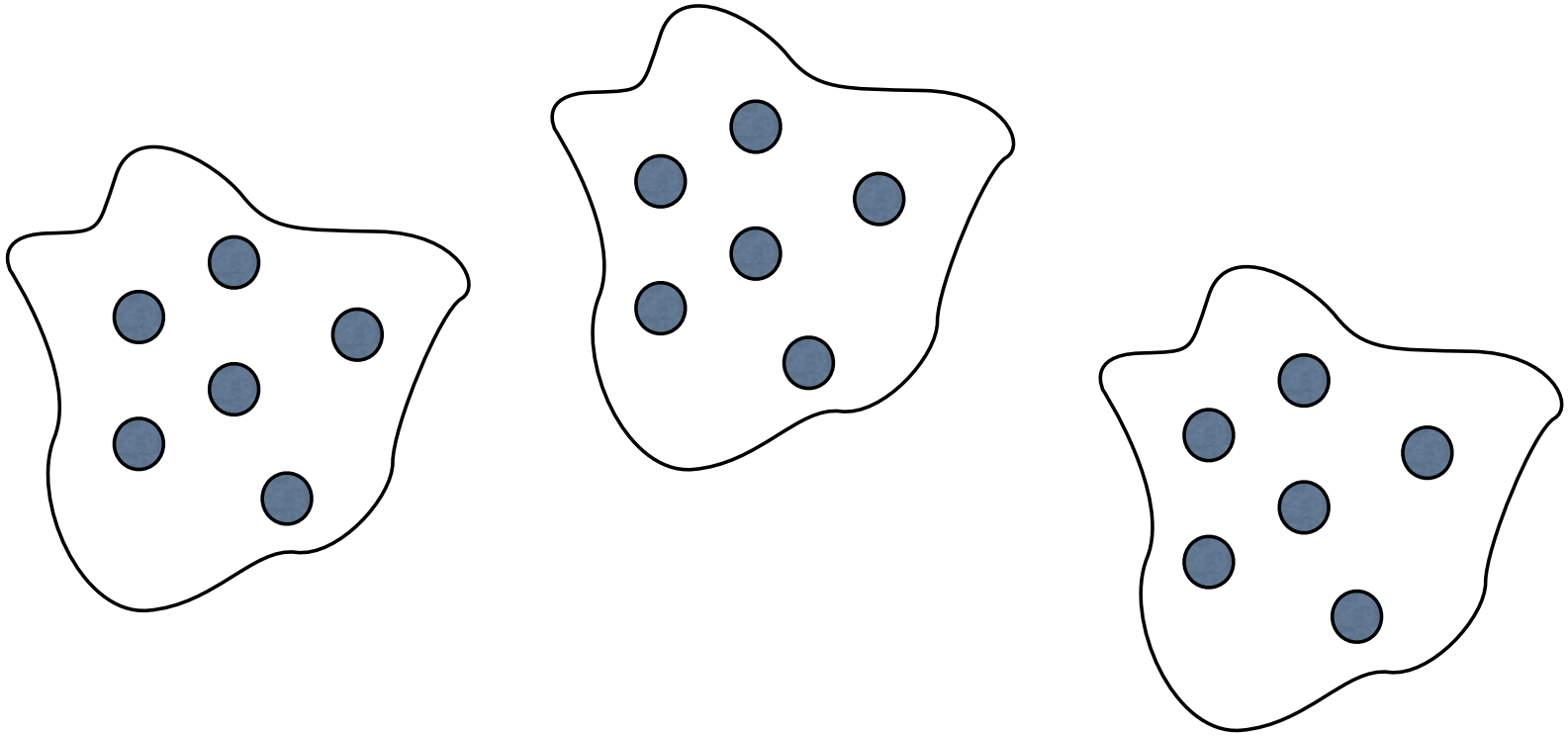
>> Demo of OHG online as soon as paper is accepted

>> All language technologies are open-source

Research Plan

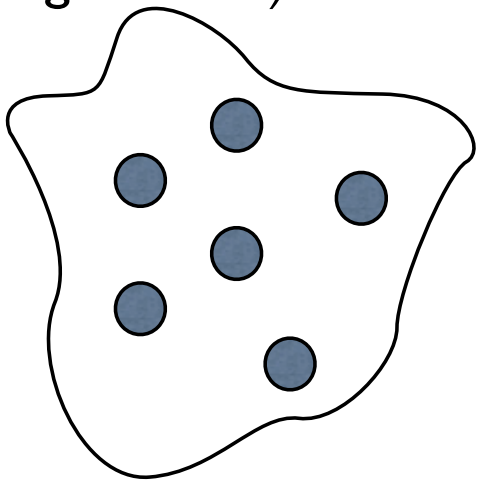
- Step 1: Bring back "alive" a language through a processing model
- **Step 2: Linguistic Assessment Criteria**
  (this presentation)

Populate speech communities of artificial agents

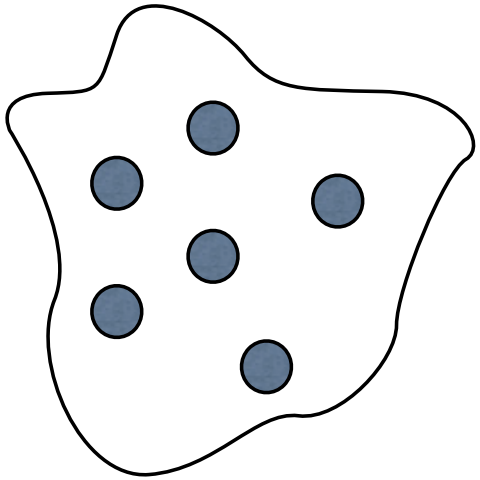


Provide agents with "reconstructed" grammar

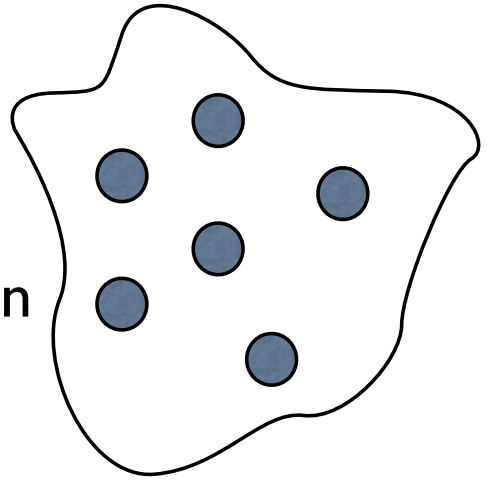
Old High German
(Wright 1906)



New High German



Texas German
(Boas 2009)



Let agents play language games

Let agents play language games

processing effort
articulatory effort
usage of memory
social conformity
communicative success
....

processing effort
cognitive effort
auditory precision
usage of memory
social conformity
communicative success
....

Comparative Reconstruction Experiment

- Three utterance types, 360 subtypes
  - 216 subtypes for ditransitive
  - 72 subtypes for Nom-Acc and 72 for Nom-Dat
- Symbolic, deep language processing model in Fluid Construction Grammar (www.fcg-net.org)

Results & Discussion

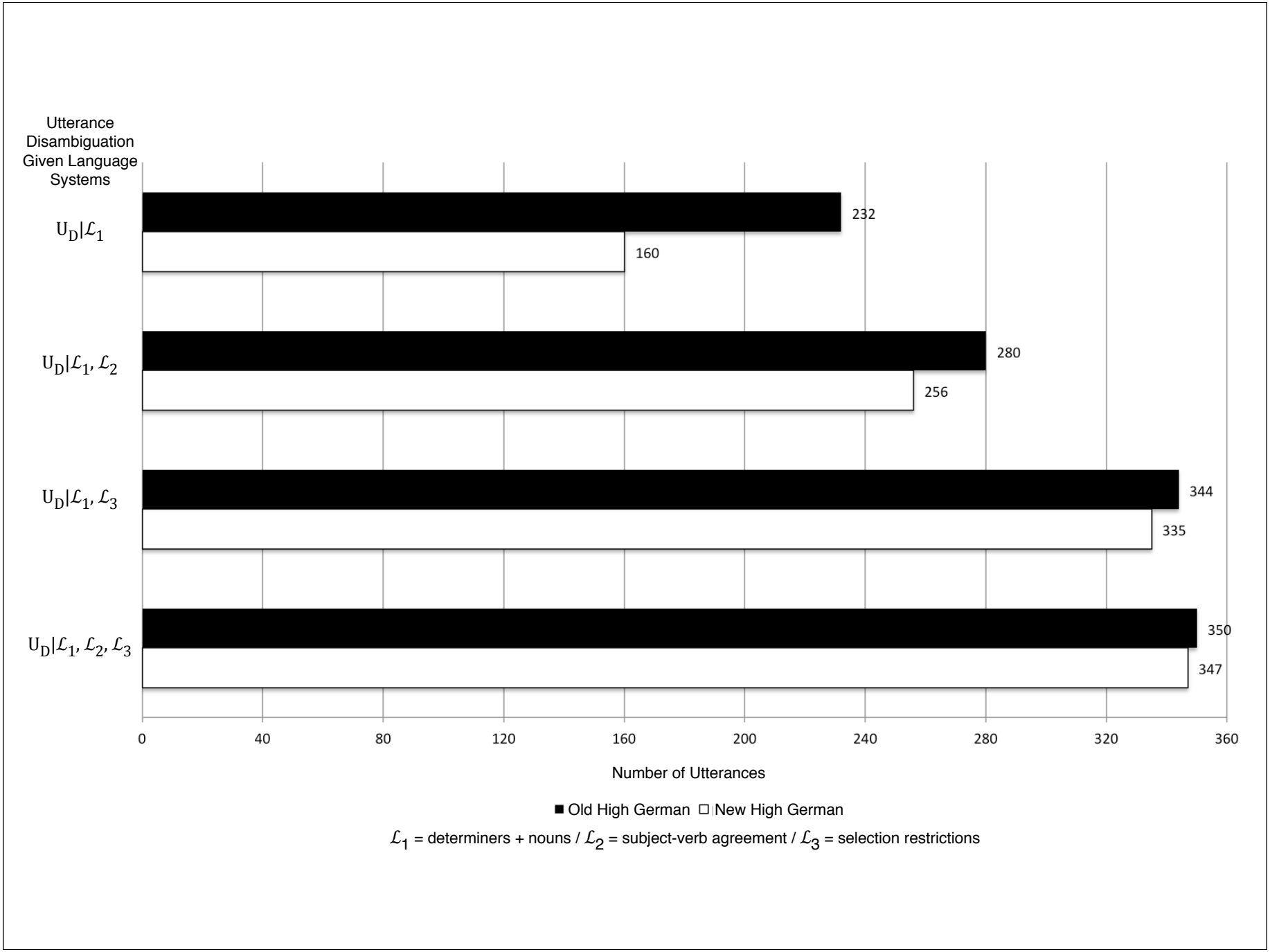
Cue Reliability & Disambiguation Power

- The **man** crossed the street.
- The fish **were** biting well that day.
- The antelope ran away when John tried to approach **them**.
- The antelope ran away.
- ...

Cue Reliability & Disambiguation Power

- A Language consists of a set of a set of language systems $\{\mathscr{L}_i, \mathscr{L}_{i+1}, \ldots, \mathscr{L}_n\}$
- Cue reliability = $(U_D|\mathscr{L}_i) / U$
- Disambiguation power = $(U_D|\ \mathscr{L}_i, \mathscr{L}_{i+1}, \ldots, \mathscr{L}_n) / U$

U = total number of utterances
U_D = number of disambiguated utterances


Utterance Disambiguation Given Language Systems
$U_D|\mathcal{L}_1$
232
160
$U_D|\mathcal{L}_1, \mathcal{L}_2$
280
256
$U_D|\mathcal{L}_1, \mathcal{L}_3$
344
335
$U_D|\mathcal{L}_1, \mathcal{L}_2, \mathcal{L}_3$
350
347
0
40
80
120
160
200
240
280
320
360
Number of Utterances
Old High German
New High German
$\mathcal{L}_1$ = determiners + nouns / $\mathcal{L}_2$ = subject-verb agreement / $\mathcal{L}_3$ = selection restrictions

Problematic utterance types

- 9 out of 10 remaining ambiguities in OHG involve plural nominative vs. accusative distinctions (*die* vs. *diu* vs. *deo*)
- This three-way distinction has disappeared from the language

Problematic utterance types

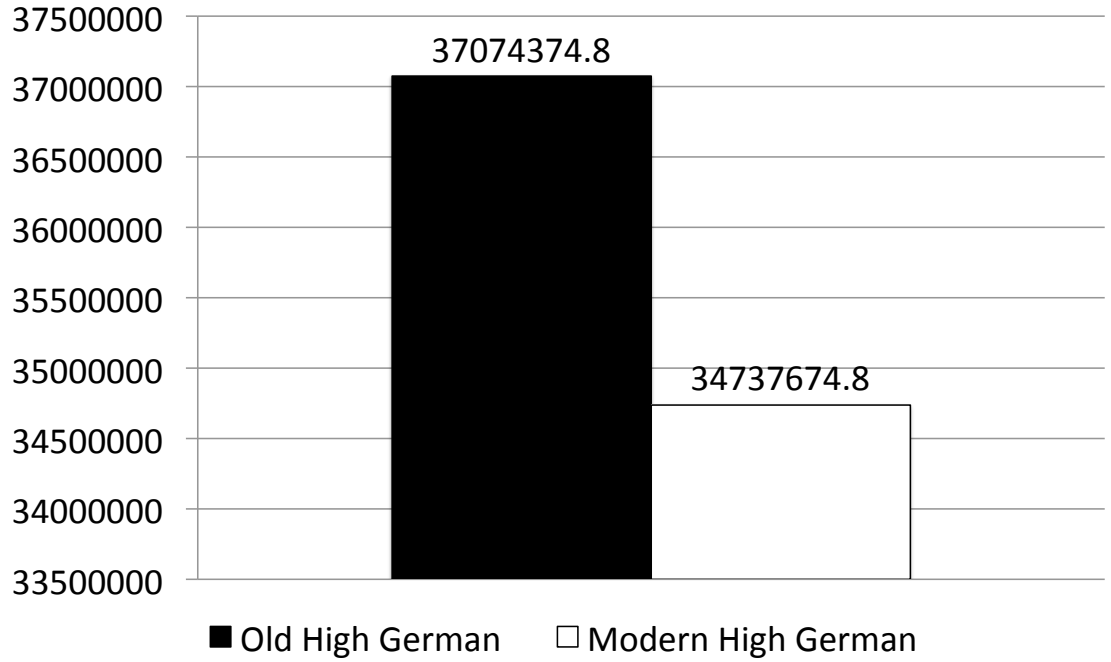
- *OHG:*
  Die Man fundun deo Friuntinnā
  the.NOM/ACC.PL the.NOM/ACC.PL
  'The men found the (female) friends.'
  'The (female) friends found the men.'
- *NHG:*
  Die Männer fanden die Freundinnen.

Processing Efficiency

- First indicator of processing efficiency: search tree length
- Counterintuitively, NHG performs equally well as OHG
- Increased syncretism does not lead to increased search (given the right representation)

Processing Efficiency

- Second indicator: how many primitive operations are needed for processing case-number-gender specifications?



- $p=2.2e\text{-}16 < 0.01$

Processing Efficiency

- The NHG-system is twice the size of the OHG-system, so it can be processed faster

$$PC(FM) = 2 \times \left(|FM| + \sum_{i=1}^{|FM|} |FV_i| \right)$$

- System size has reduced without harming disambiguation power

Ease of Articulation

- Speech = balance between ease of articulation and intelligibility (ease of perception)

	die		das		
Phonemes	d	i:	d	a	s
Syllabic	–	–	–	+	–
Continuant	–		–		+
Sonorant	–		–		–
Nasal	–		–		–
Voice	+		+		–
Anterior	+		+		+
Coronal	+		+		+
Lateral	–		–		–
High	–	+	–	–	–
Low		–		+	
Back	–	–	–	+	–
Rounded		–		–	
Long		+		–	

Ease of Articulation

- Articulatory effort = cost of moving from one articulator to another (~ edit distance)

	die		das		
Phonemes	d	i:	d	a	s
Syllabic	–	–	–	+	–
Continuant	–		–		+
Sonorant	–		–		–
Nasal	–		–		–
Voice	+		+		–
Anterior	+		+		+
Coronal	+		+		+
Lateral	–		–		–
High	–	+	–	–	–
Low		–		+	
Back	–	–	–	+	–
Rounded		–		–	
Long		+		–	

Ease of Articulation

- Articulatory effort = cost of moving from one articulator to another (~ edit distance)

Old High German												
	Singular						Plural					
	Masc		Neut		Fem		Masc		Neut		Fem	
NOM	*dër*		*daz*		*diu*		*die*		*diu*		*deo*	
	24	0.6757	26	0.6486	20	0.7297	18	0.7568	20	0.7297	18	0.7568
ACC	*dën*		*daz*		*die*		*die*		*diu*		*deo*	
	24	0.6757	26	0.6486	18	0.7568	18	0.7568	20	0.7297	18	0.7568
DAT	*dëmu*		*dëmu*		*dëru*		*dēn*		*dēn*		*dēn*	
	40	0.4595	40	0.4595	40	0.4595	24	0.6757	24	0.6757	24	0.6757

New High German												
	Singular						Plural					
	Masc		Neut		Fem		Masc		Neut		Fem	
NOM	*der*		*das*		*die*		*die*		*die*		*die*	
	24	0.6757	26	0.6486	14	0.8108	14	0.8108	14	0.8108	14	0.8108
ACC	*den*		*das*		*die*		*die*		*die*		*die*	
	24	0.6757	26	0.6486	14	0.8108	14	0.8108	14	0.8108	14	0.8108
DAT	*dem*		*dem*		*der*		*den*		*den*		*den*	
	24	0.6757	24	0.6757	24	0.6757	24	0.6757	24	0.6757	24	0.6757

Ease of Articulation

- "Expensive" articles in OHG: *dëmu* and *dëru* have been shortened in NHG (*dem* and *der*)
- Diphthongs (*die*, *diu*, *deo*) have been simplified to less costly long vowel (*die*)

Auditory Efficiency

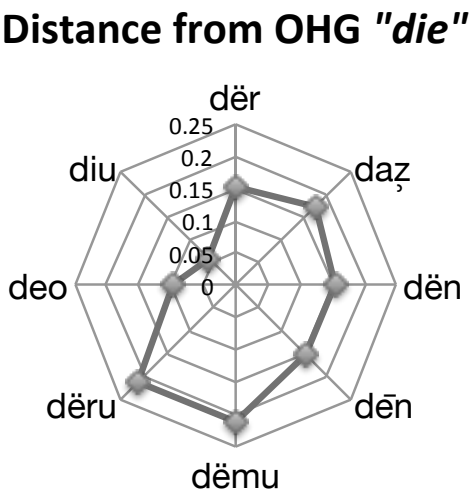
- How easily can articles be distinguished from each other in perception?
- Similarly measured as an edit distance
- Distance between closest neighbors

d	i:	–
d	a	s

Auditory Efficiency

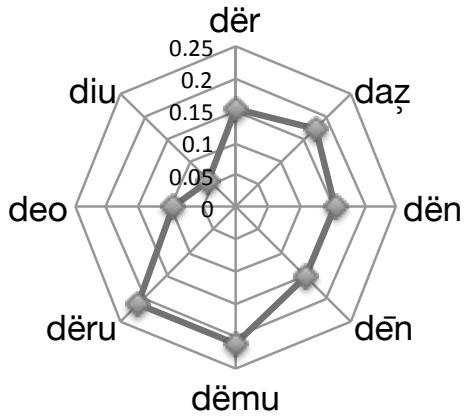
- Results: In NHG, the distance between articles that are hard to distinguish from each other has increased...
- But only if disambiguation power remained unharmed!

Auditory Efficiency

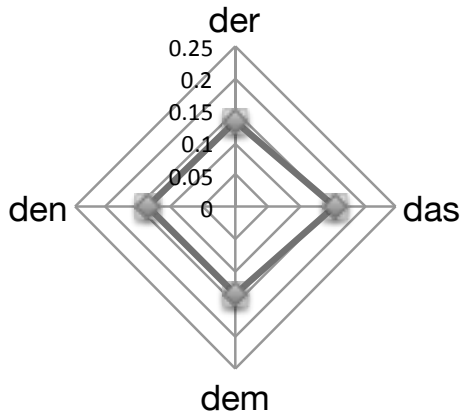


Auditory Efficiency

Distance from OHG *"die"*

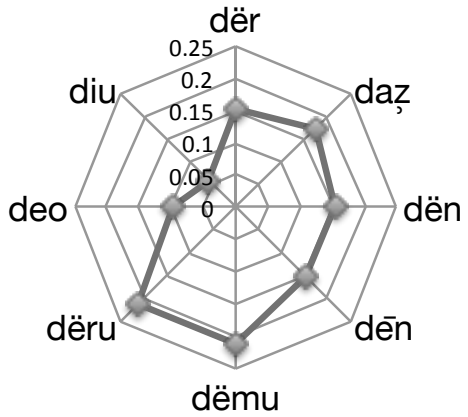


Distance from NHG *"die"*

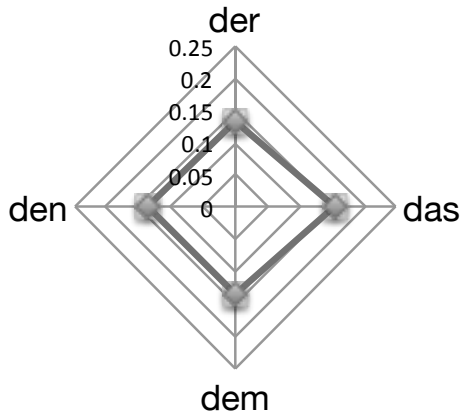


Auditory Efficiency

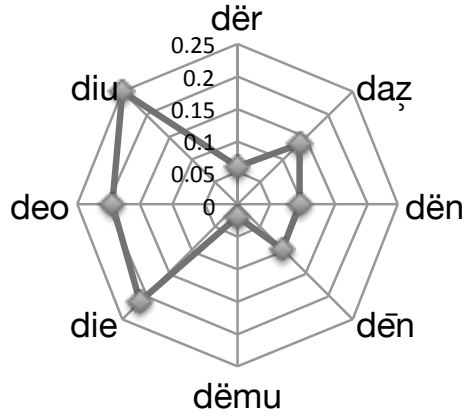
Distance from OHG *"die"*



Distance from NHG *"die"*

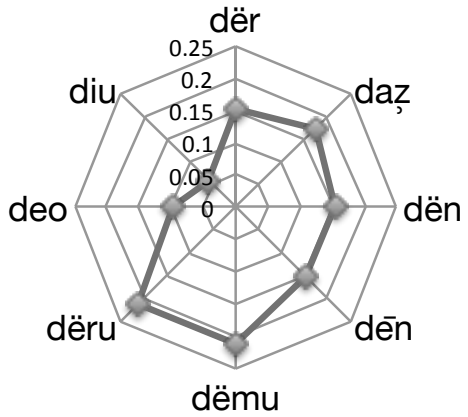


Distance from OHG *"dëru"*

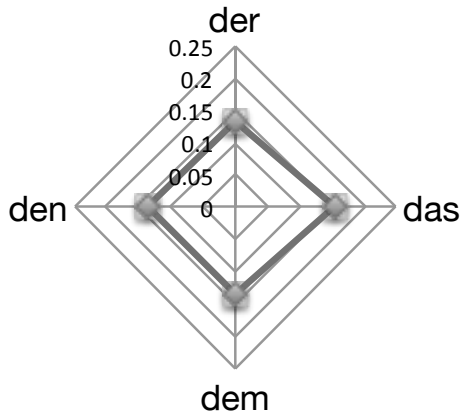


Auditory Efficiency

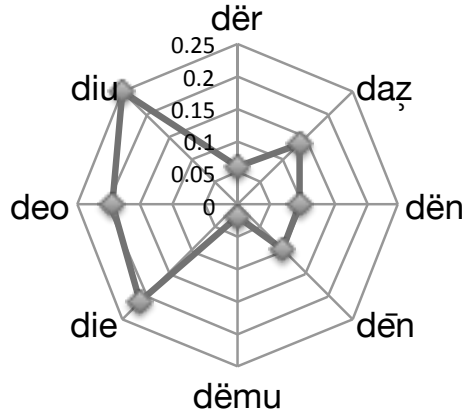
Distance from OHG *"die"*



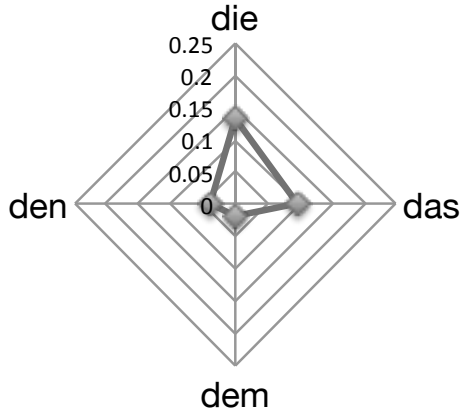
Distance from NHG *"die"*



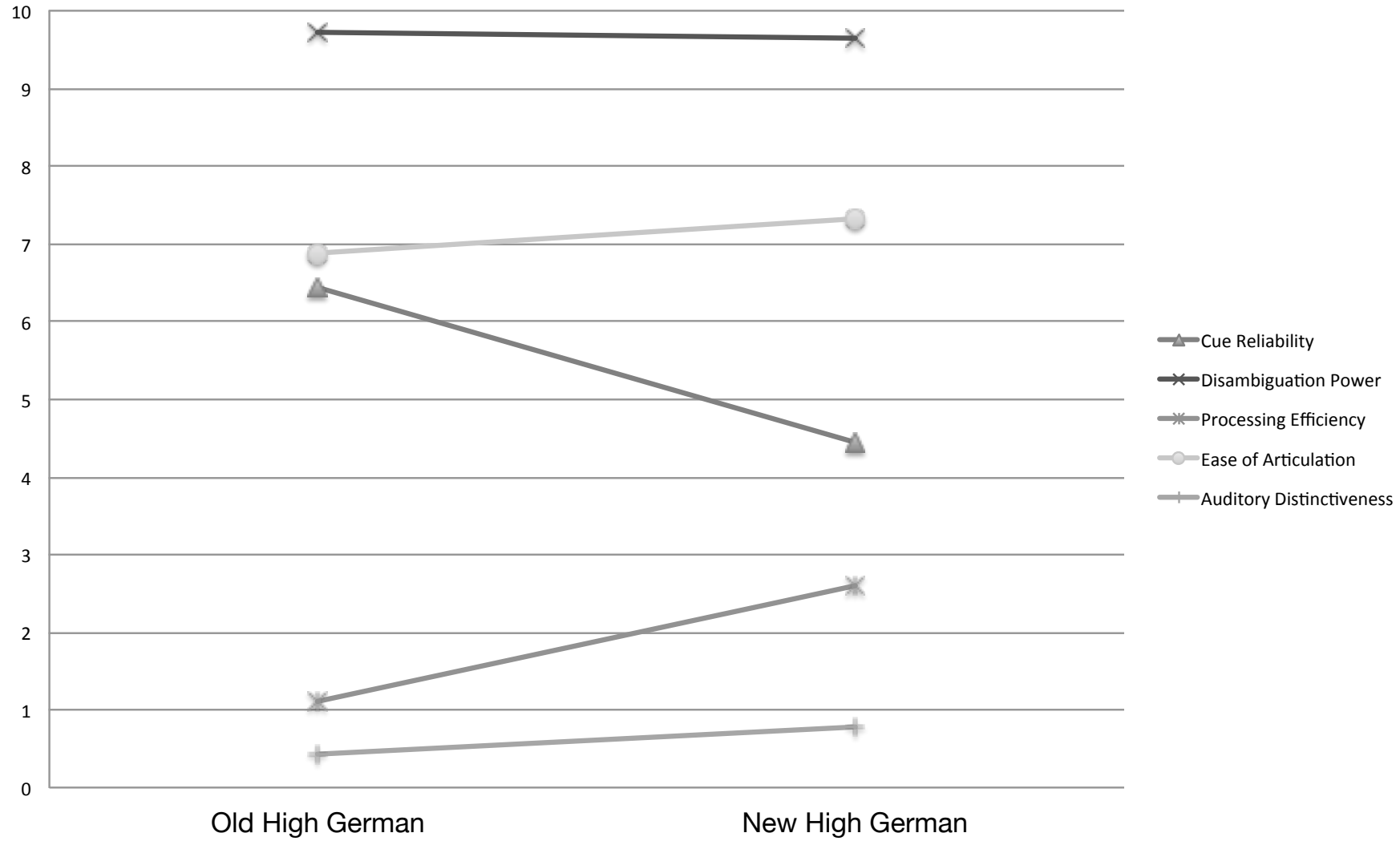
Distance from OHG *"dëru"*



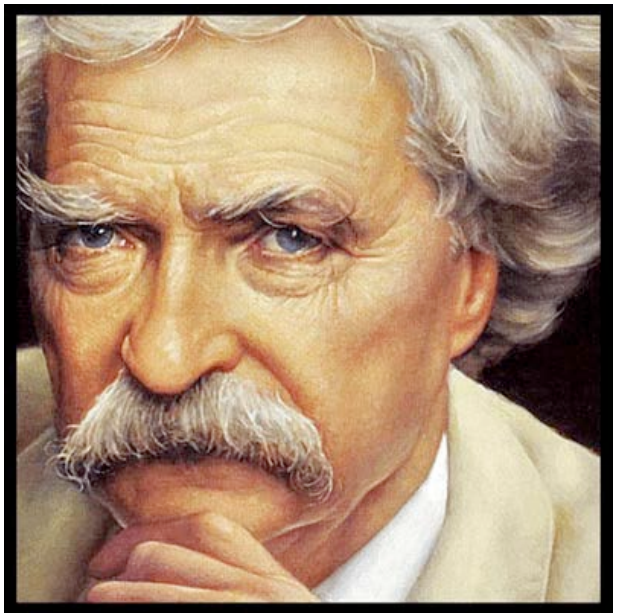
Distance from NHG *"der"*



Summary


10
9
8
7
6
5
4
3
2
1
0
Old High German
New High German
Cue Reliability
Disambiguation Power
Processing Efficiency
Ease of Articulation
Auditory Distinctiveness

That Awful German Language



Mark Twain, 1835-1910

"Surely there is not another language that is so slipshod and systemless, and so slippery and elusive to the grasp."

Not that awful after all!

- Evolution of German definite articles was no accident...
- ... it was motivated by needs and constraints of language users.
- But what happened precisely? And why?

Formulating a more precise hypothesis

- **Variation** is inevitable in a speech **population**
- The German "linguistic ecosystem" changed
  - > Most syncretisms emerged by the Middle Ages when the demonstrative had grammaticalized into an article...
  - > ... so an additional cue became available in the NP's head noun
- Syncretic forms were **selected** because they had become more advantageous for language usage (in the new ecosystem)

Background reading

- Steels, Luc (ed., 2012). *Experiments in Cultural Language Evolution*. Amsterdam: John Benjamins.
- http://ai.vub.ac.be
- http://www.emergent-languages.org
- http://www.fcg-net.org

Thank you!

Questions? Comments?

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