Lessons learned in computational modeling of language learning and conceptual change

Timo Honkela

Aalto University
(former Helsinki University of Technology)

Department of Information and Computer Science
Cognitive Systems research group

Finland

ConChaMo 4: Modeling Conceptual Change
Espoo, 20 Feb 2013

A short introduction of the speaker

Natural language database interface with dependency-based compositional semantics

- H. Jäppinen, T. Honkela, H. Hyötyniemi & A. Lehtola (1988): A Multilevel Natural Language Processing Model. Nordic Journal of Linguistics 11:69-87.

What is the turnover of the ten largest stock exchange companies in forestry?

Morphological analysis

Dependency parsing

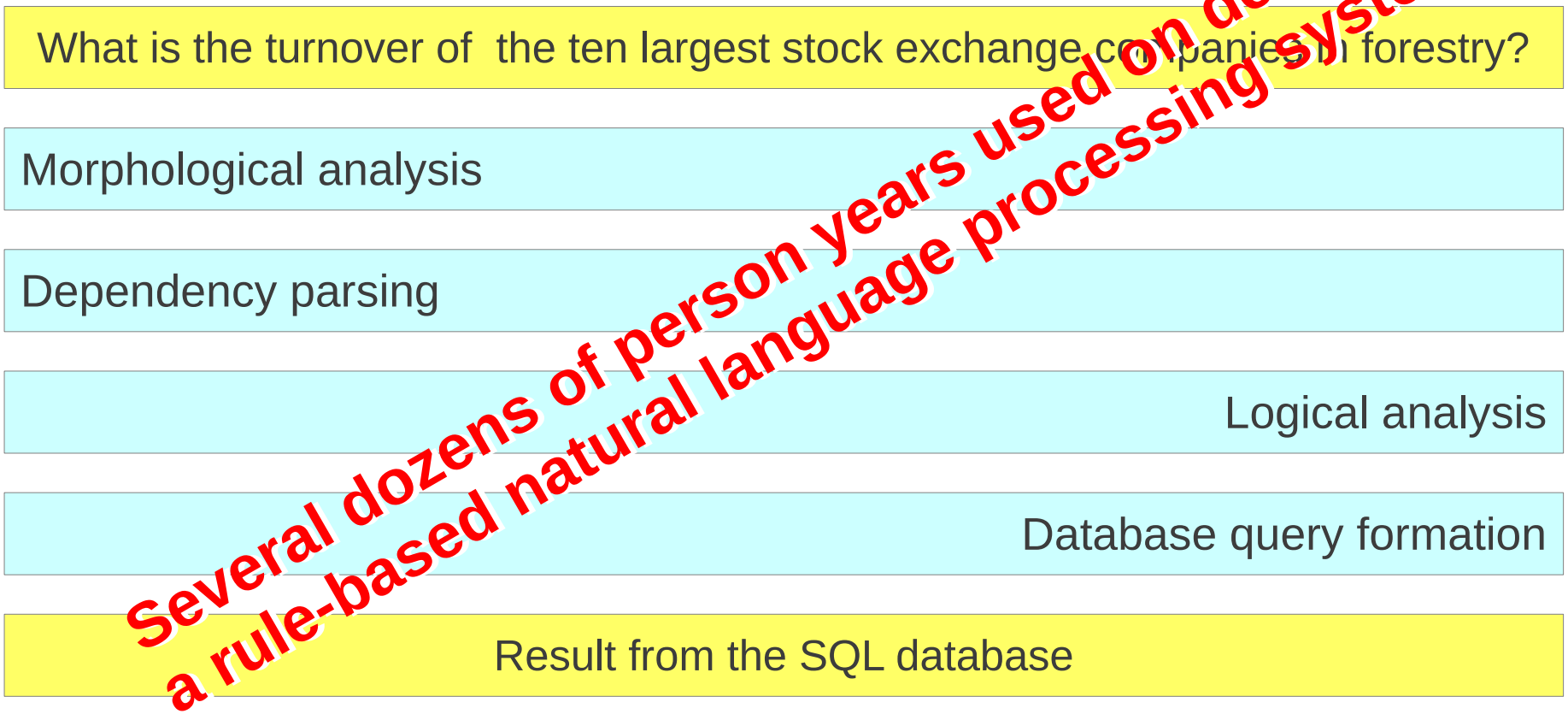
Logical analysis

Database query formation

Result from the SQL database

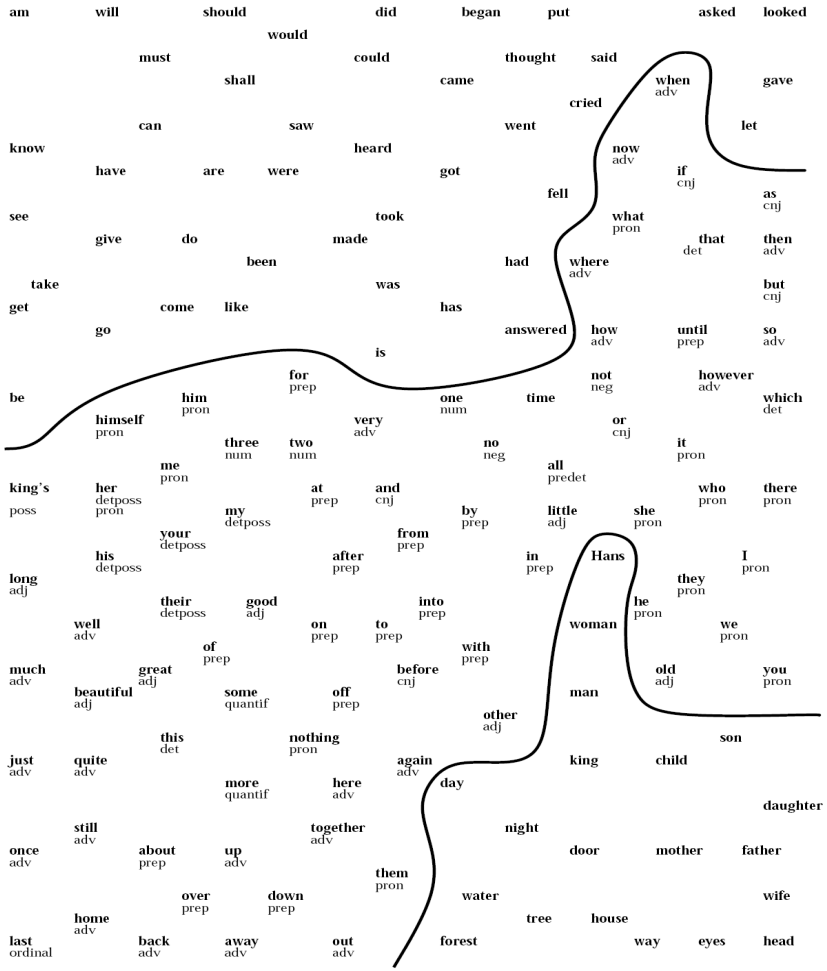
Natural language database interface with dependency-based compositional semantics

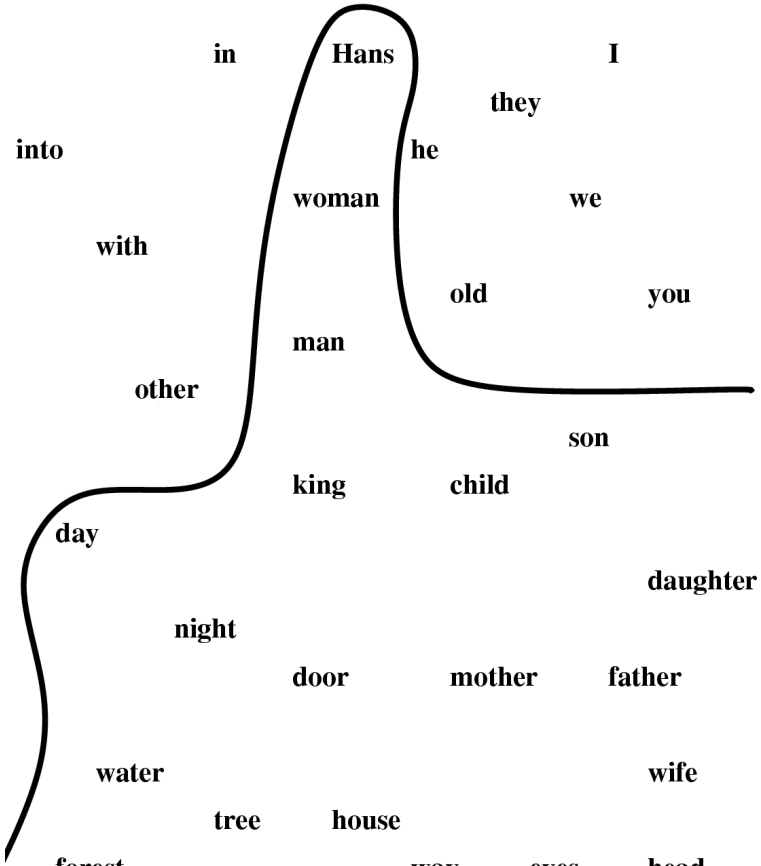
- H. Jäppinen, T. Honkela, H. Hyötyniemi & A. Lehtola (1988): A Multilevel Natural Language Processing Model. Nordic Journal of Linguistics 11:69-87.



Several dozens of person years used on developing a rule-based natural language processing system.

Classical example: Learning meaning from context:
Maps of words in Grimm fairy tales





Honkela, Pulkki & Kohonen 1995

Classical example: Learning meaning from context:
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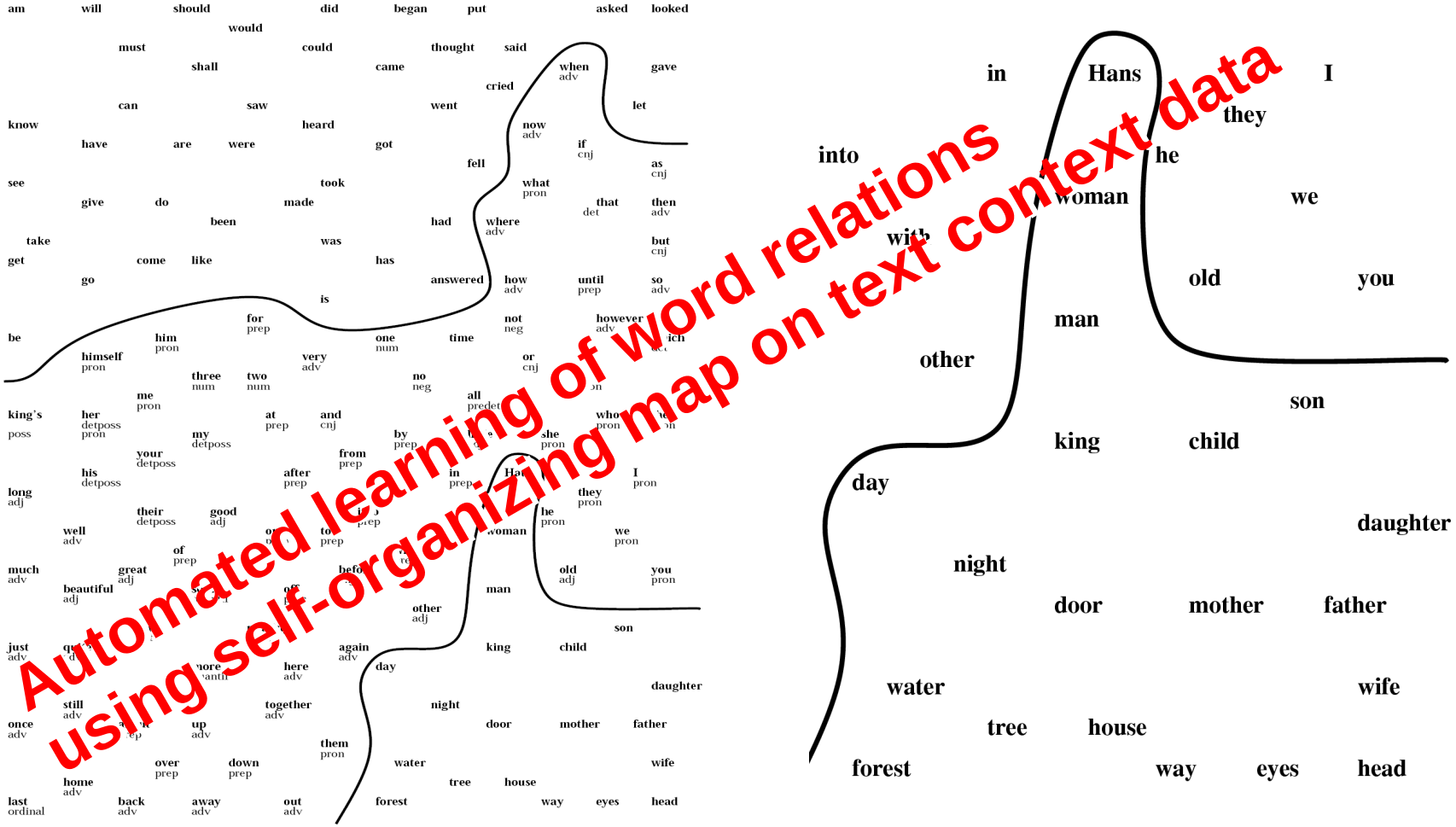


Honkela, Pulkki & Kohonen 1995

Concept Formation and Communication - General Theory

C_i: N-dimensional metric **concept space**

S: symbol space, The **vocabulary** of an agent that consists of discrete symbols

$\lambda : C_i \times C_j \rightarrow R, i \neq j$
A **distance** between two points **in** the **concept spaces** of different agents

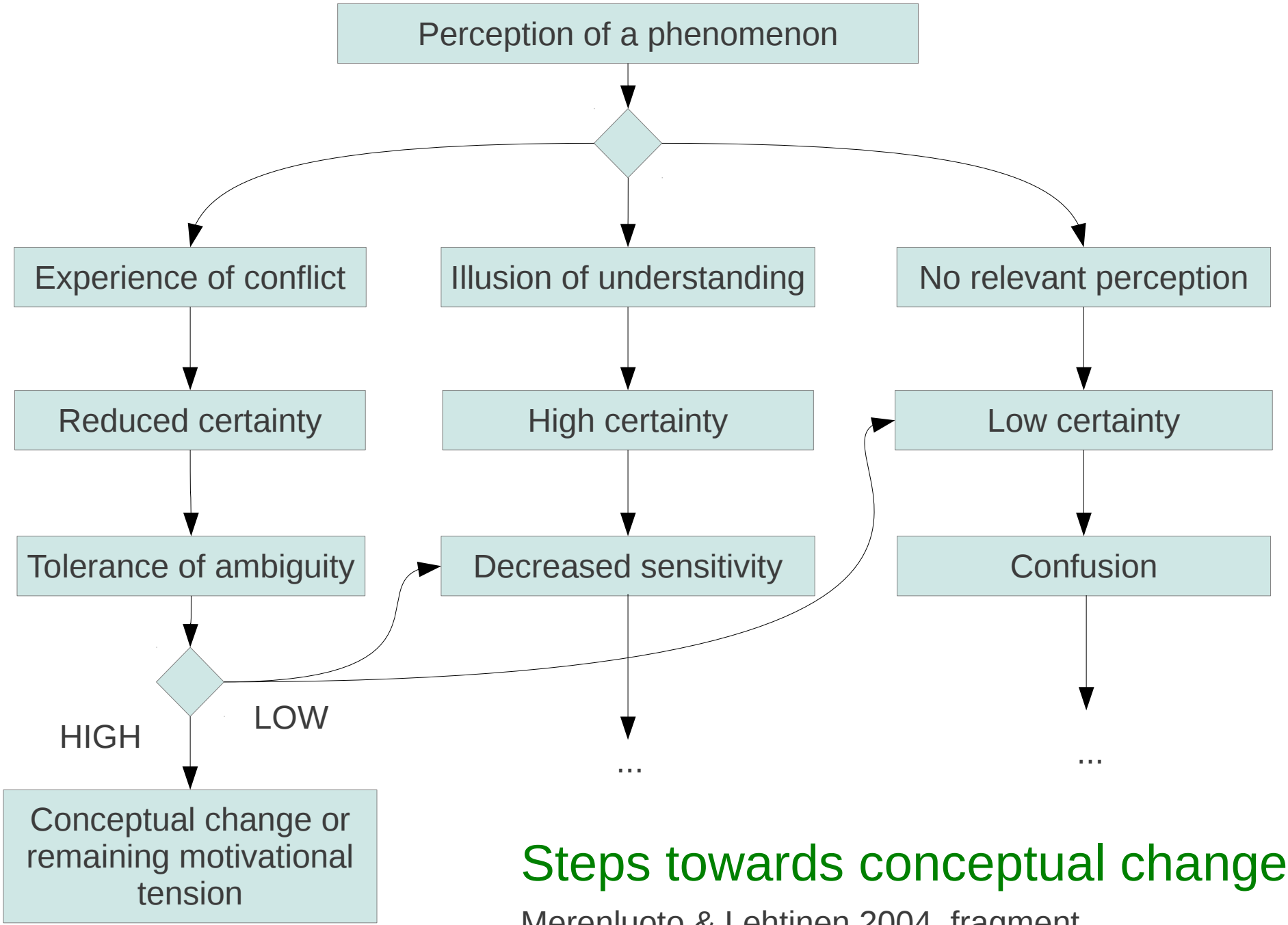
$\xi: s_i \in S_i \rightarrow C$
An individual **mapping** function **from symbols to concepts**

$\varphi_i: S_i \rightarrow D$
An individual **mapping from** agent i's **vocabulary to** the **signal space** D and an inverse mapping $\varphi^{-1}{}_i$ from the signal space to the symbol space

Observing f_1 and after symbol selection process, agent 1 communicates a symbol s* to agent 2 as signal d. When agent 2 observes d, it maps it to some $s_2 \in S_2$ by using the function $\varphi^{-1}{}_1$. Then it maps the symbol to some point in its concept space by using ξ_2. If this point is close to its observation f_2 in the sense of λ, the communication process has succeeded.

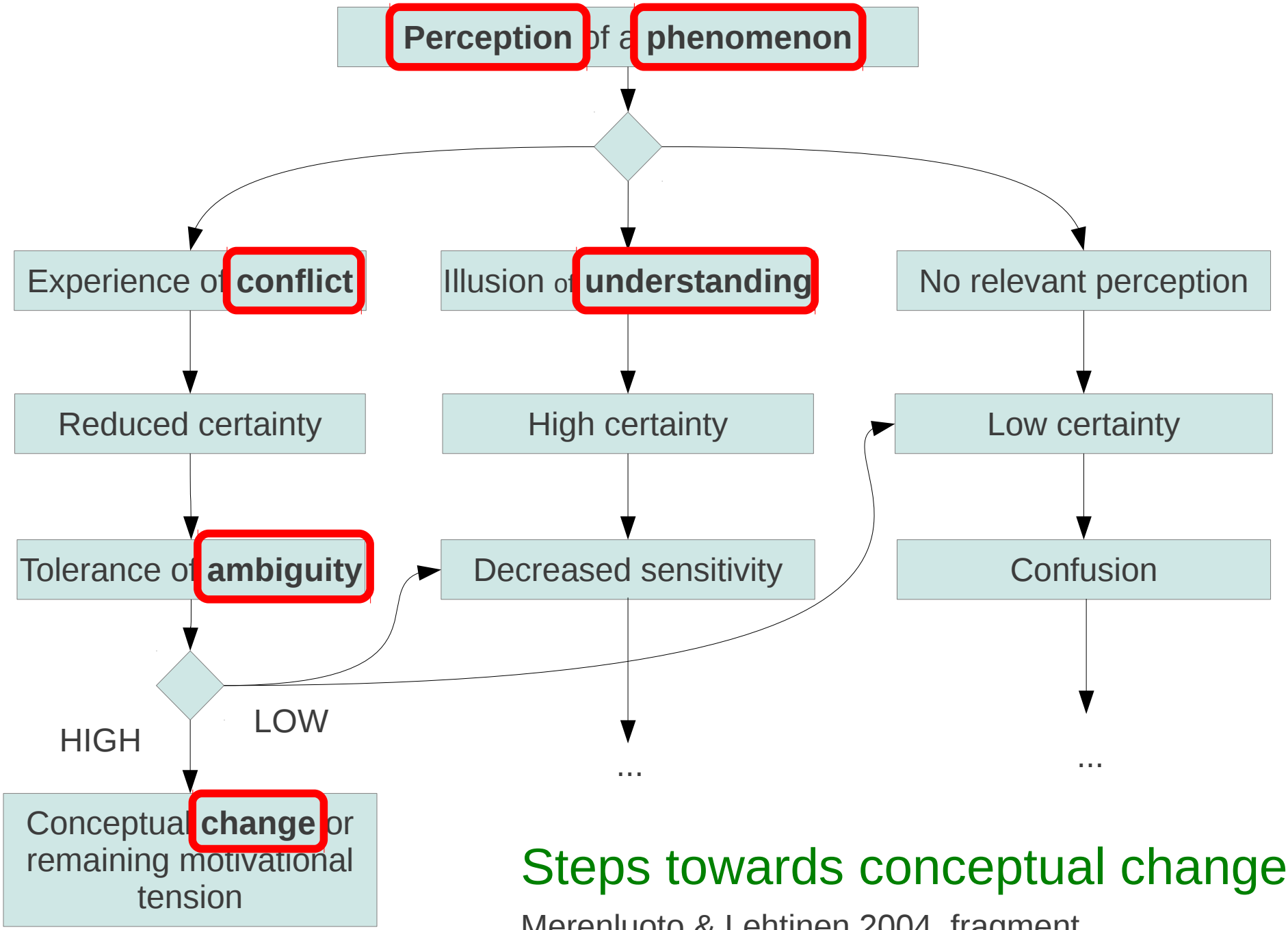
Timo Honkela, Ville Könönen, Tiina Lindh-Knuutila, and Mari-Sanna Paukkeri. Simulating processes of concept formation and communication. Journal of Economic Methodology, 15(3):245–269, **2008**.

Elements of conceptual change



Steps towards conceptual change

Merenluoto & Lehtinen 2004, fragment



Steps towards conceptual change

Merenluoto & Lehtinen 2004, fragment

Key concepts

- Concept
- Phenomenon
- Perception
- Understanding
- Conflict / ambiguity
- Change

Key concepts

- Concept
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Computational means to model these concepts?

Review of

Computational and theoretical tools: CONCEPT

Concept of a concept:
representational alternatives

- Symbols, relations (predicates), inference rules, ...
- Set theory, algebra of sets, ...
- Graph theory, partitioning, decomposition, ...
- Vector spaces, matrices, tensors, matrix and tensor algebra, ...
- Probability theory, Bayesian inference, …
- Functional analysis, convolution, ...

Concept of a concept:
alternative frameworks

- Logic-based and cognitive
  - Semantic nets
  - Frame systems
- Intermediate
  - Neural theory of language
- Biologically inspired
  - Neural networks
    - Self-organizing semantic maps
    - Semantic pointers

Concepts – Language

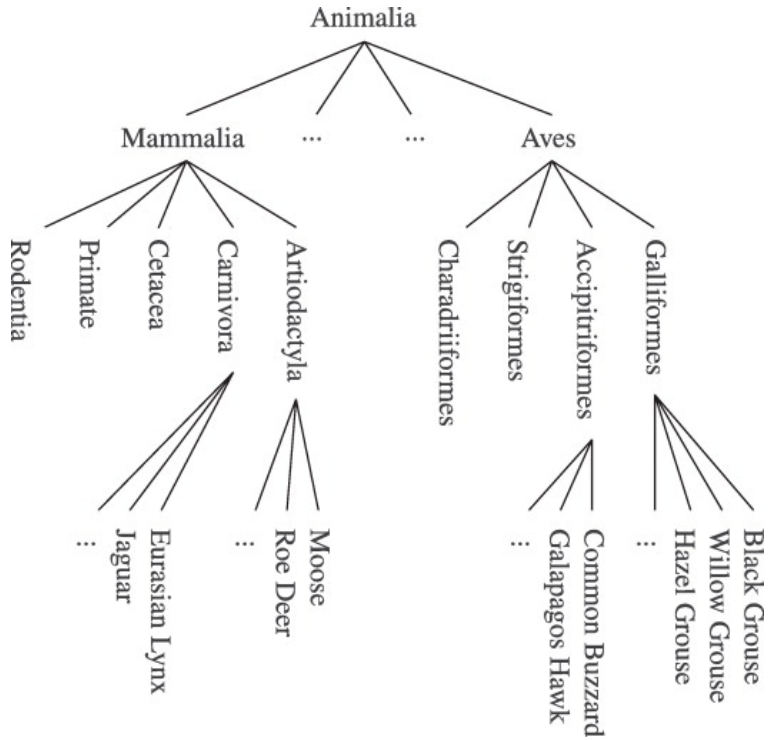
- Essential question:
  What is the relation between concepts and language?
- One view: “According to Language of Thought Hypothesis, thought and thinking are done in a mental language, i.e., in a symbolic system physically realized in the brain” (e.g. Fodor) *
- Another view: “a formalism necessary and sufficient for a theory of communication must not contain primary symbols representing communicabilia (e.g. symbols, words, messages, etc.” (Von Foerster, 1972/1981) **

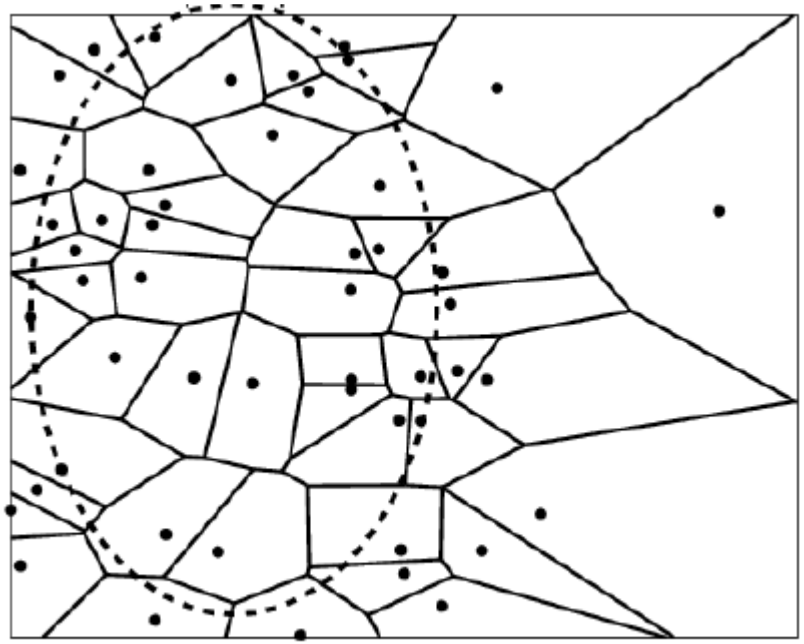
* http://plato.stanford.edu/entries/language-thought/

** http://www.univie.ac.at/constructivism/pub/hvf/papers/honkela05kohonen.pdf

Concept of a conceptual system

- Symbols, relations
- Vector spaces: Voronoi tessellation





http://users.ics.aalto.fi/tho/online-papers/TKK-ICS-R24.pdf

http://www.sciencedirect.com/science/article/pii/S1568494611004340

Review of

Computational and theoretical tools: PHENOMENON

Phenomenon

- Essential question:
  What are our ontological assumptions like?
- One view: “Elementary propositions are immediate combinations of semantically simple symbols or 'names'; Names refer to items wholly devoid of complexity, so-called 'objects'; Atomic states of affairs are combinations of these simple objects.” (Wittgenstein: Tractatus) *
- Another view: “Objects and events are not primitive experiences. Objects and events are representations of relations. Since ’objects’ and ’events’ are not primary experiences and thus cannot claim to have absolute (objective) status, their interrelations, the ’environment’ is a purely personal affair, whose constraints are anatomical or cultural factors.” (Von Foerster, 1972/1981) **

* http://plato.stanford.edu/entries/wittgenstein-atomism/

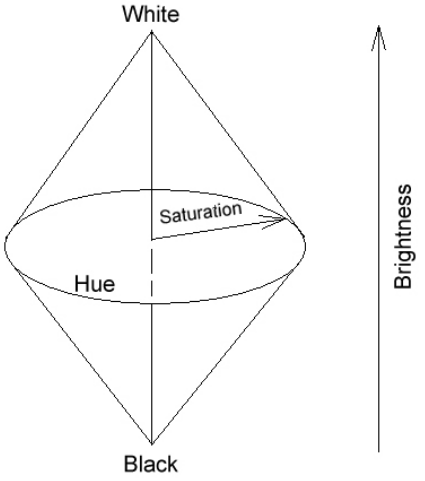
** http://www.univie.ac.at/constructivism/pub/hvf/papers/honkela05kohonen.pdf

Relevance of this ontological question to computational modeling

- Can phenomena be represented adequately within the same language or symbol set as language/concepts/communication?

The statement “snow is white” is true iff snow is white.

vs.



Question of adequacy

- In many cases, using only “linguistic grounding” is sufficient for practical purposes and for the moment perhaps the only realistic approach
- However, if accuracy of theory building and/or realistic applications are aimed at, proper symbol grounding is necessary; regrettably much of the theoretical and practical work in conceptual modeling falls short in this respect.

Review of

Computational and theoretical tools: PERCEPTION – AND MOVEMENT

Why brains?

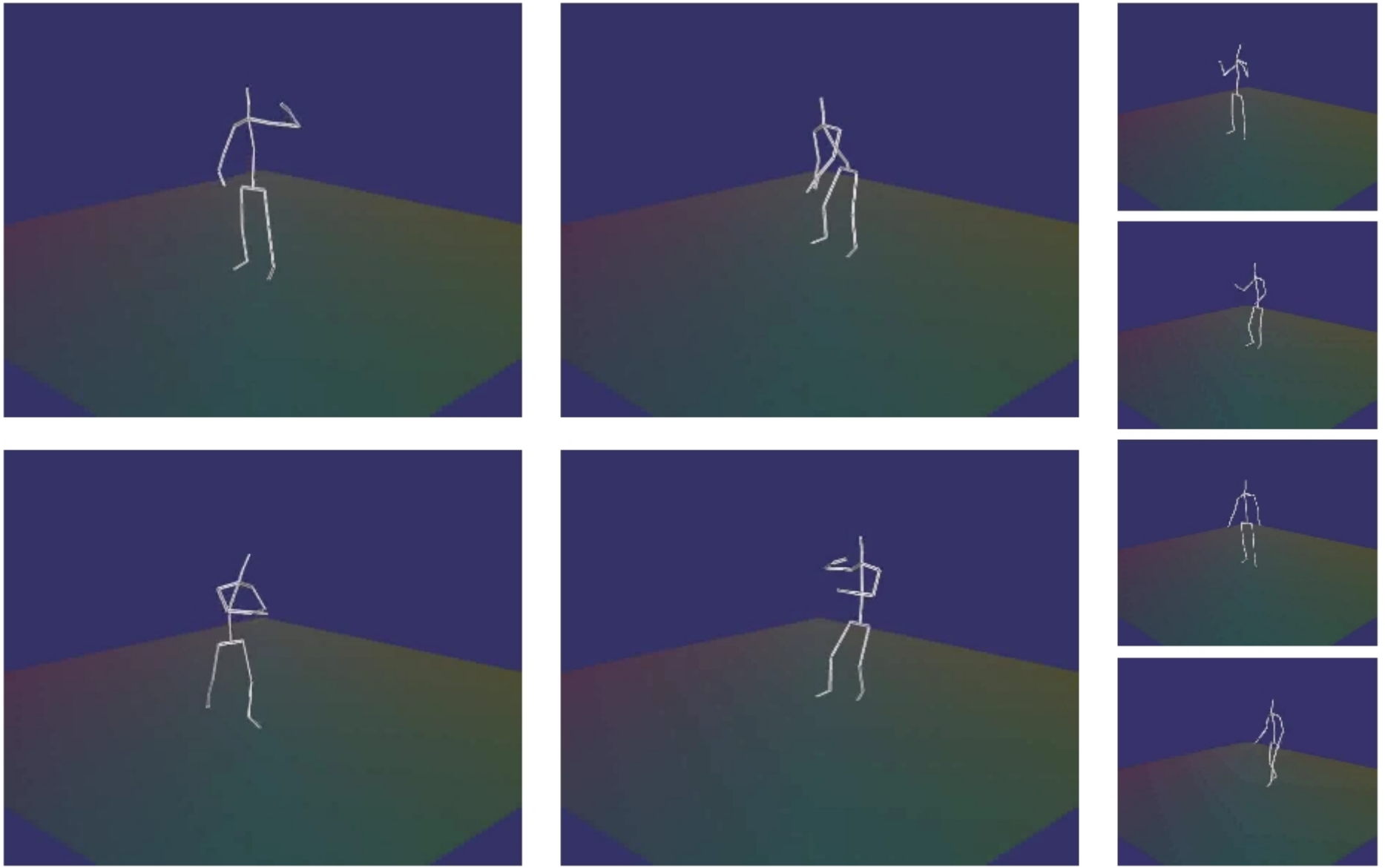
- What are the central differences between plants and animals?

  “The original need for a nervous system was to coordinate **movement**, so an organism could go find food, instead of waiting for the food to come to it.” http://www.fi.edu/learn/brain/

- An extreme example: A sea squirt transforms from an “animal” to a “plant”. It absorbs its own cerebral ganglion that it used to swim about and find its attachment place.

http://goodheartextremescience.wordpress.com/2010/01/27/meet-the-creature-that-eats-its-own-brain/

Human movement



David Bailey's thesis (1997):

Verbs related to **hand** movement

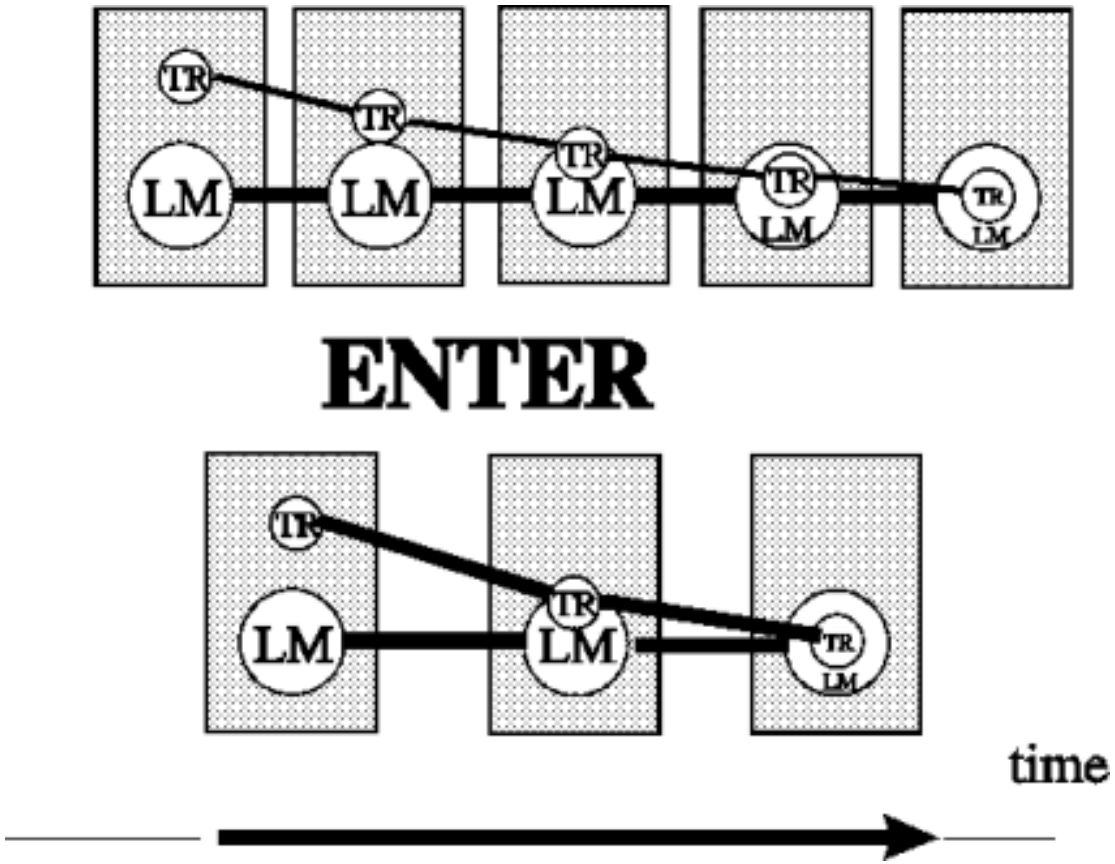
get, seize, snatch, grab, grasp, pick (up), take, hold, grip, clutch, put, place, lay, drop, slam, release, let go, move, push, pull, shove, yank, slide, bat, flick, tug, nudge, lift, raise, hoist, lower, pass over, lob, toss, throw, fling, whip, chuck, hit, tap, rap, bang, slap, press, poke, punch, rub, shake, pry, turn (over), flip (over), tip (over), rotate, spin, twirl, handle, squeeze, pinch, tie, twist, bend, bounce, scrape, scratch, scrub, smear, crush, smash, shatter, scatter, spread (out/on), cut, slice, clip, wipe, brush, grind, tighten, loosen, open, close, insert, remove, hook, hang, balance, peel, (un)wind, dunk, (un)zip, juggle, knead, dribble, scribble, hand, pass, salute, caress, fondle, pet, pat, stroke, wave, point, hide, stack, touch, feel, reach (for), stop, help, resist, try, bump, slip, knock (over/down)

Point of view from cognitive linguistics

Aalto University

- The meaning of linguistic symbols in the mind of the language users derives from the users' sensory perceptions, their actions with the world and with each other.
- For example: the meaning of the word 'walk' involves
  - what walking looks like
  - what it feels like to walk and after having walked
  - how the world looks when walking
    (e.g. objects approach at a certain speed, etc.).
  - ...

Abstract vs concrete grounding



Ronald Langacker

Multimodally Grounded Language Technology

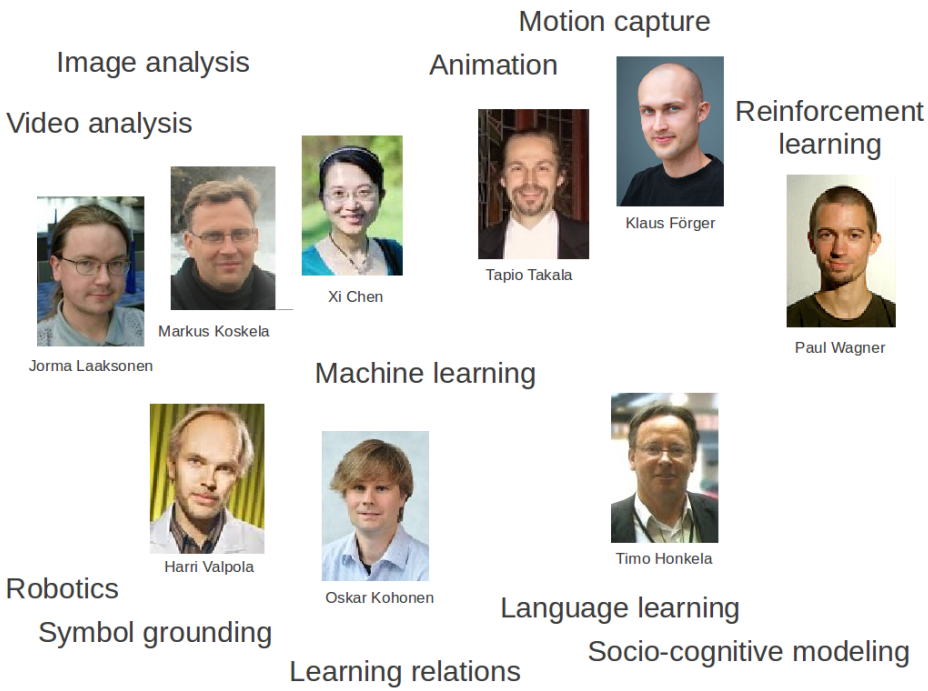
A project funded by Academy of Finland 2011-2014

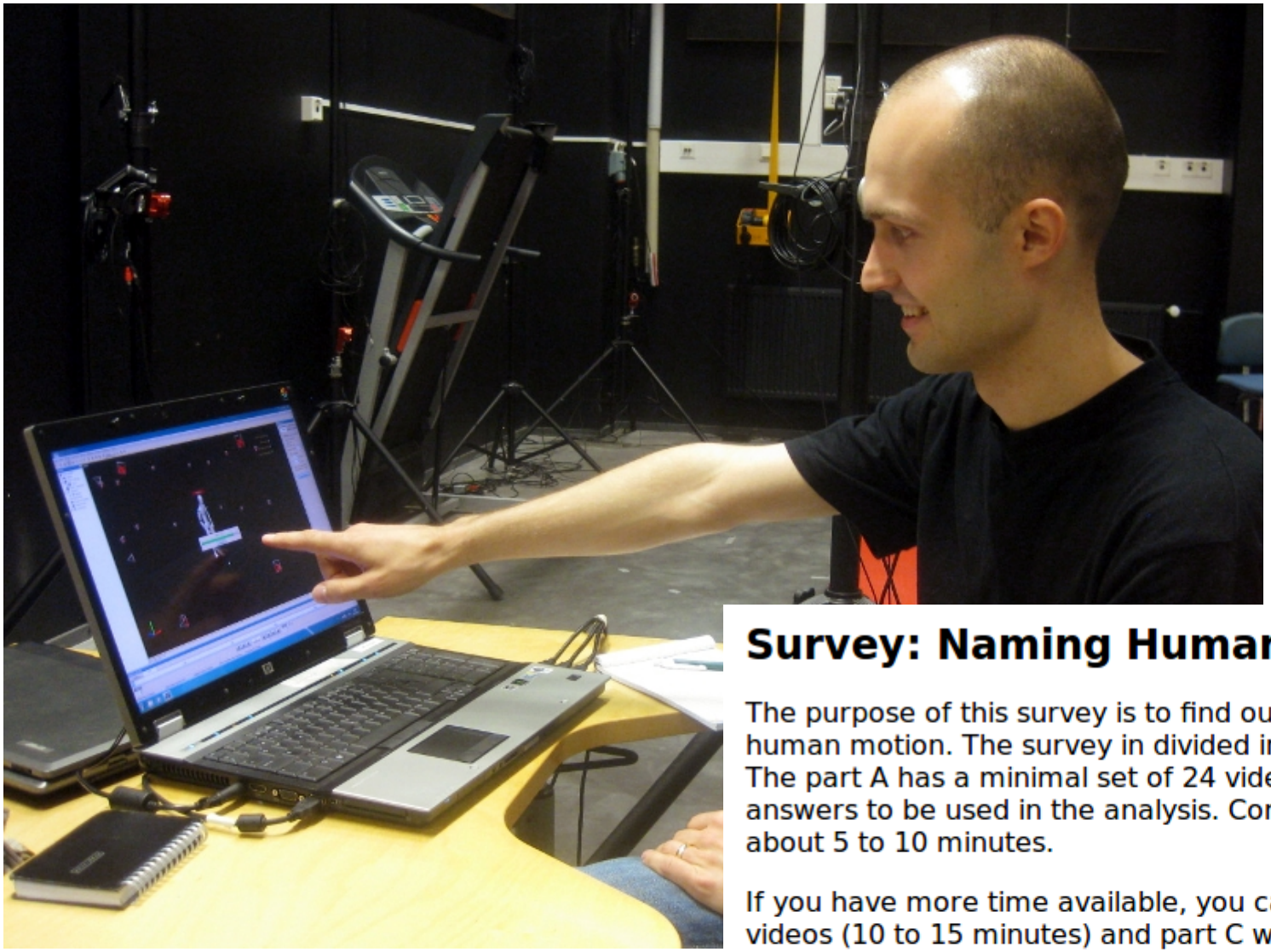
Timo Honkela as the Principal Investigator

A collaboration between departments of

* Information and Computer Science, and

* Media Technology





Survey: Naming Human Movement

The purpose of this survey is to find out how people describe human motion. The survey in divided in to three parts A, B and C. The part A has a minimal set of 24 videos that enables your answers to be used in the analysis. Completing the part A will take about 5 to 10 minutes.

If you have more time available, you can continue to part B with 40 videos (10 to 15 minutes) and part C with 60 videos (15 to 20 minutes). Answering only to the part A is already valuable to the research, but we hope that you would also consider answering the parts B and C.

First you are asked to fill in a background questionnaire. Then the task is to watch a moving character in a set of videos and to write a verb and optionally some adjectives that describes the seen motion.

goo.gl / UZnvH

Labeling movements

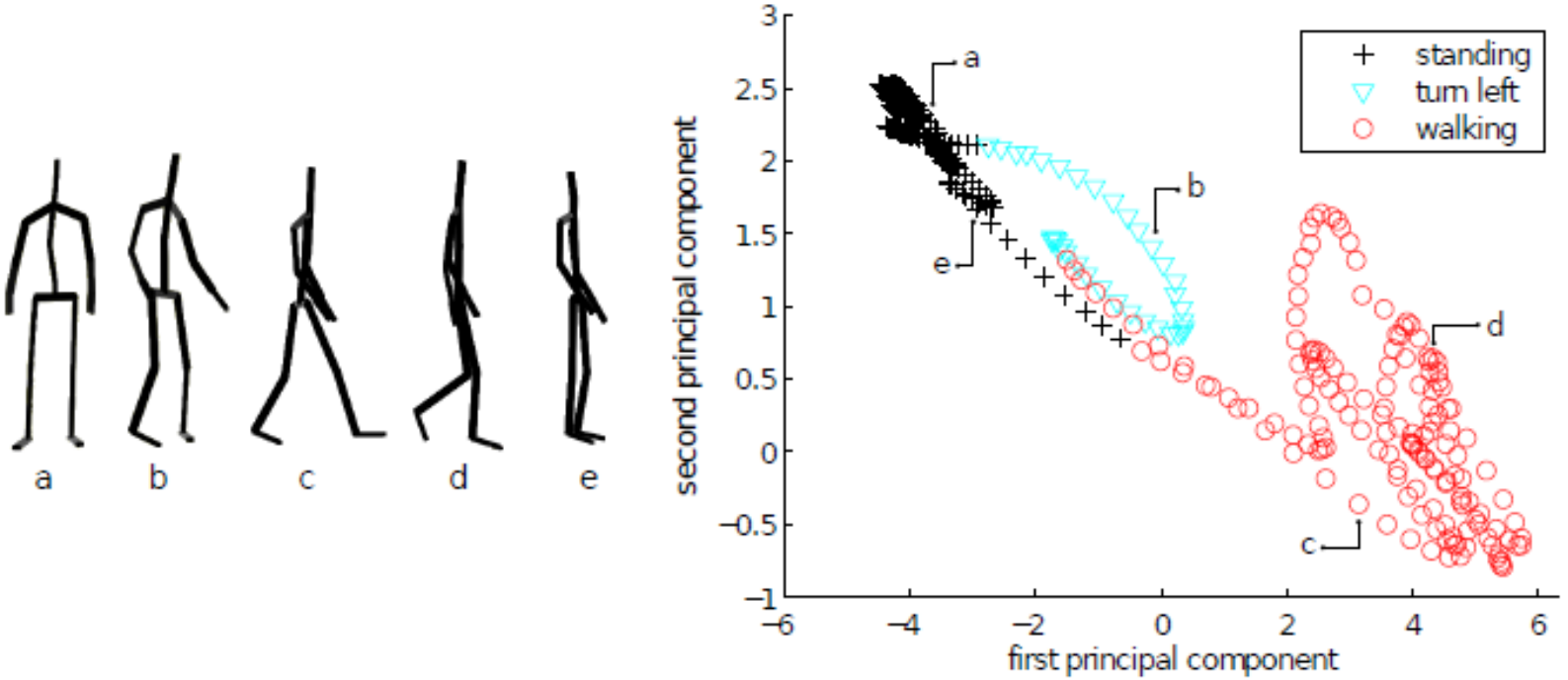
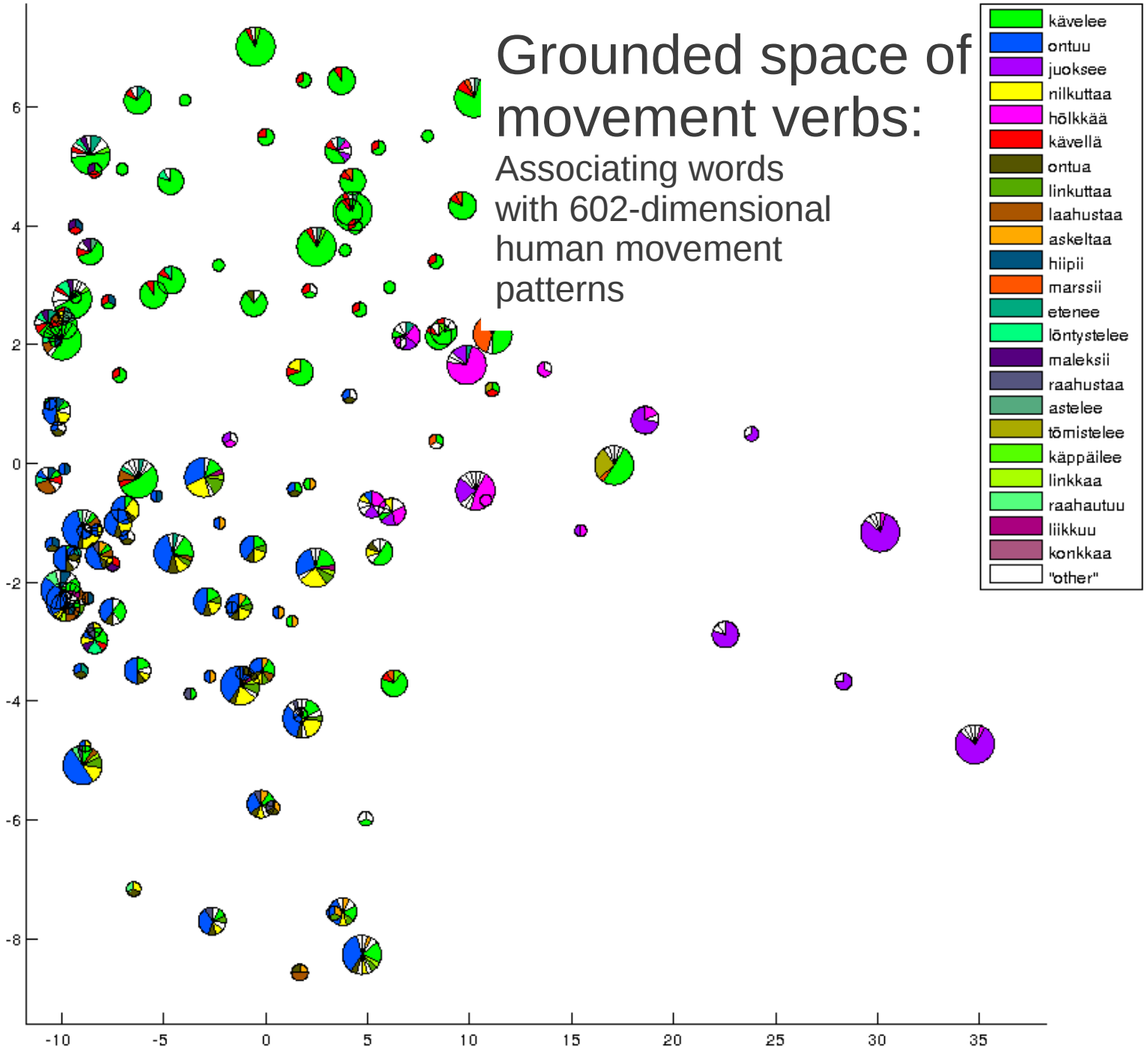


Fig. 11 Motion of a character standing (a), turning (b), walking (c, d) and again standing (e) as stick figures (left) and the trajectory formed by the frames on plotted on the first and second principal component (right).

From an unpublished manuscript. Experiments by Klaus Förger.

Grounded space of movement verbs:

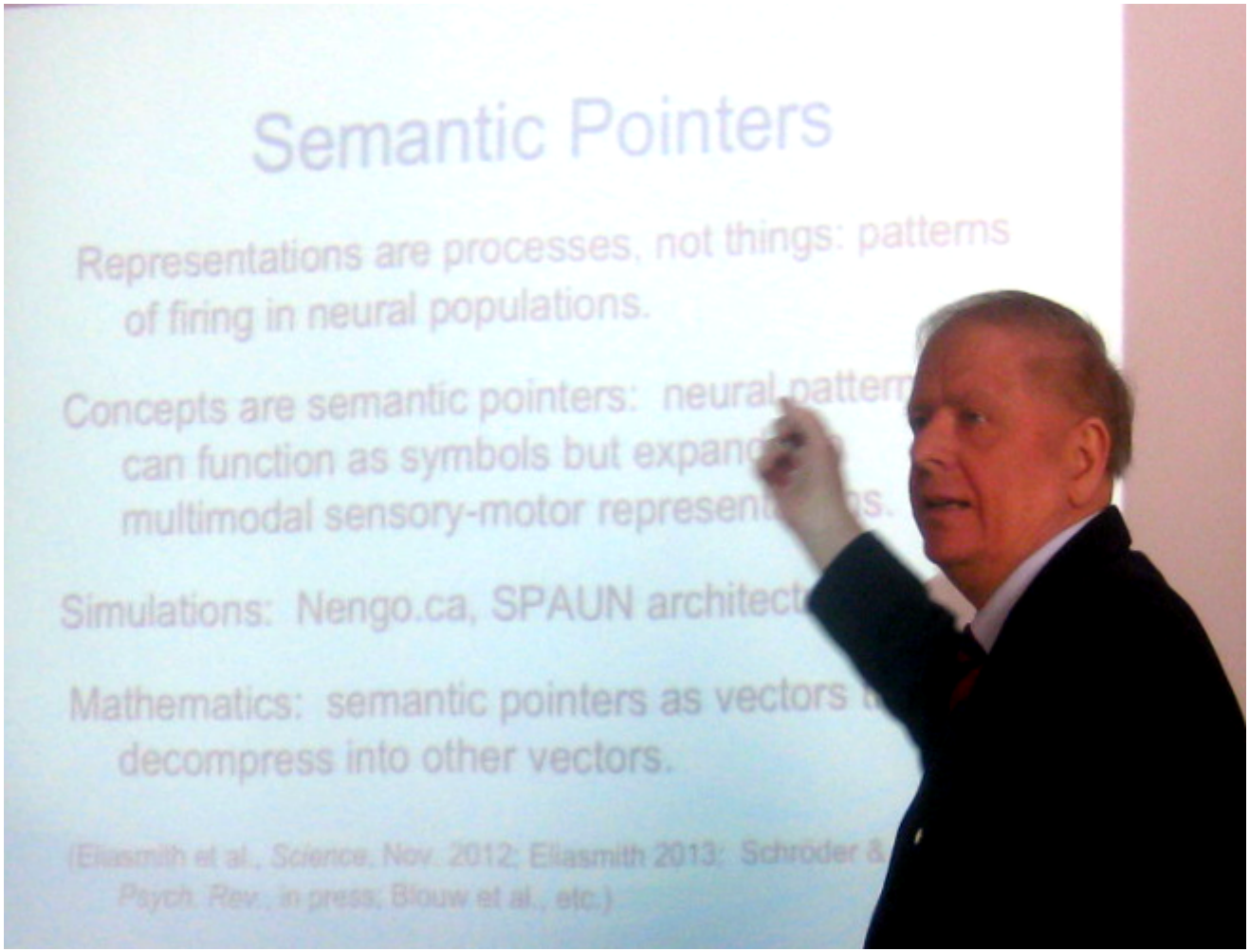
Associating words with 602-dimensional human movement patterns



Walk
Limb
Run
…
Jog
Walk
…
March
…

From an unpublished manuscript. Experiments by Klaus Förger and Timo Honkela.

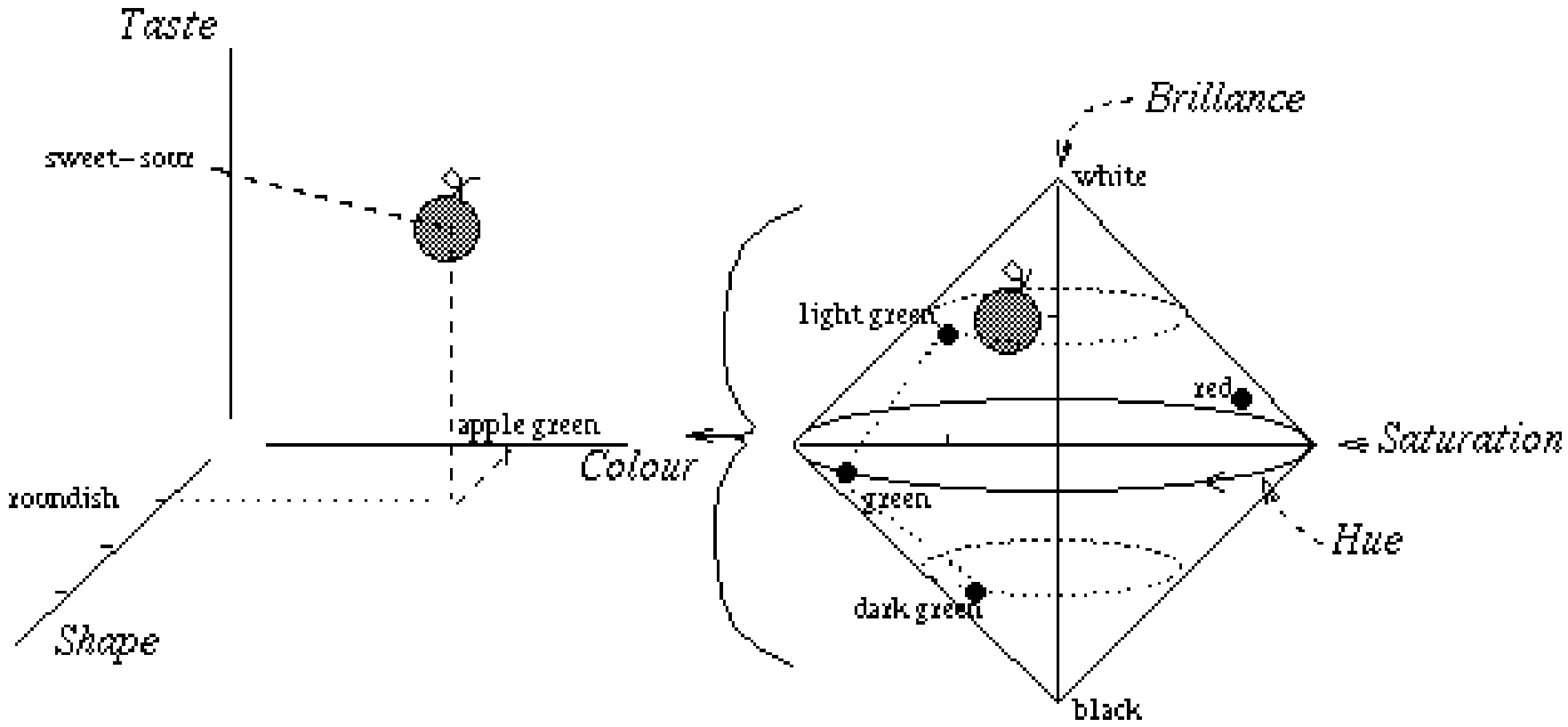
Concepts and representations as processes!



Conceptual spaces

- A convenient way to consider linking level of symbols, concepts and raw perception is the theory conceptual spaces
- Gärdenfors' presentation tomorrow is built on conceptual spaces theory and therefore not dealt with in detail here

Conceptual spaces – example



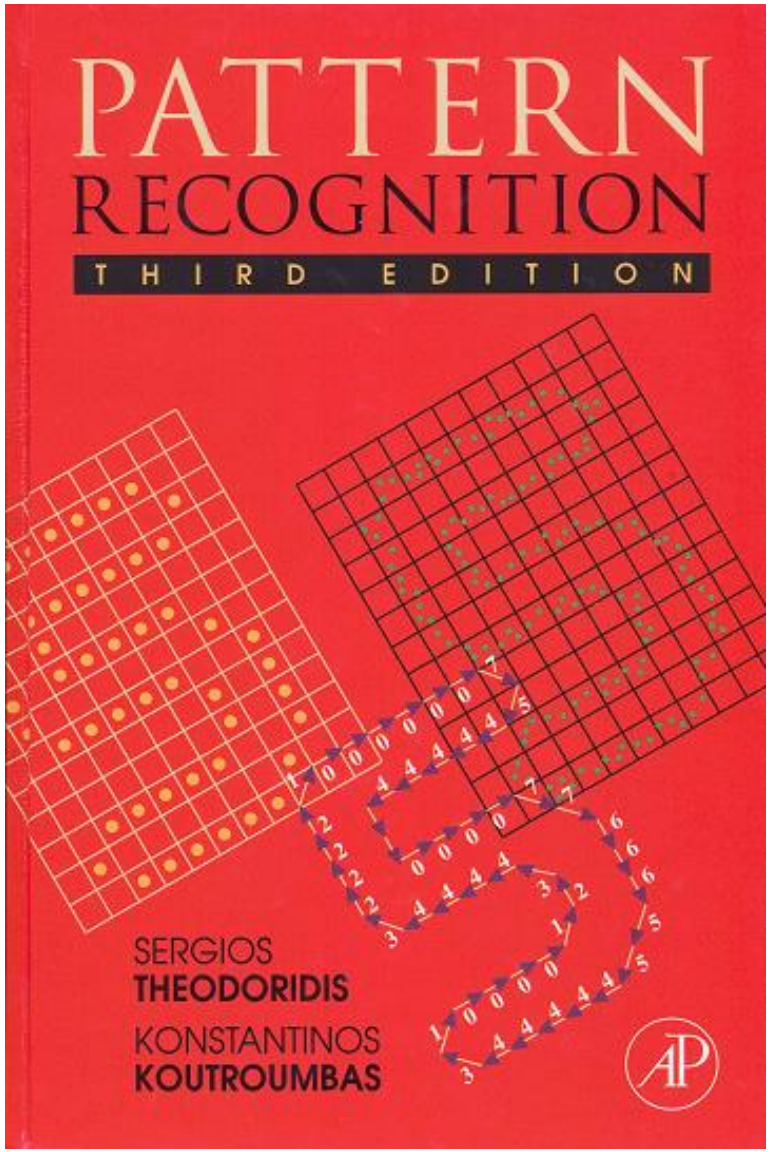
Harmsze (2000)

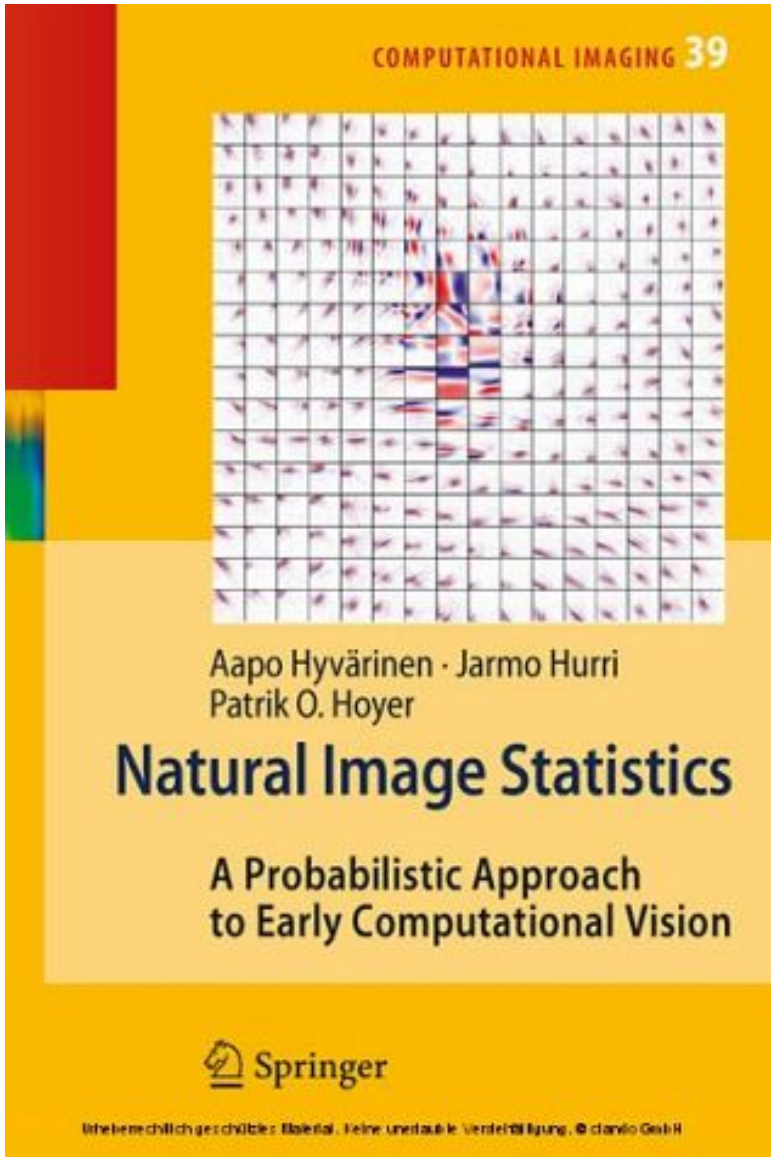
http://www.science.uva.nl/projects/commphys/papers/thesisfh/chapters/node35.html

Perception

- When something (a complex pattern of sensed reality – phenomenon) is perceived as something (e.g, an instance of a concept), a mapping from a high-dimensional space to another high-dimensional takes place.
- The first space is typically complex in the sense that there is a lot of information, much of which is irrelevant from the point of view of the task at hand
- The representation in the second space is sparse – an essential factor that enables communication using a limited set of symbols

Suggested reading





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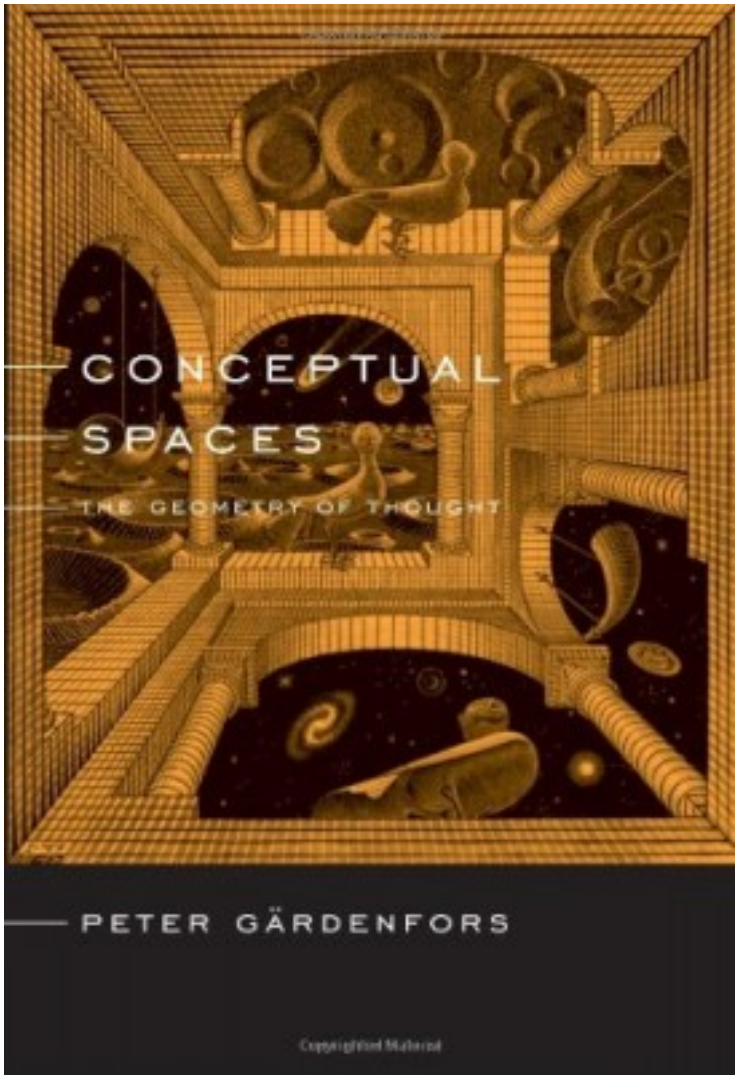
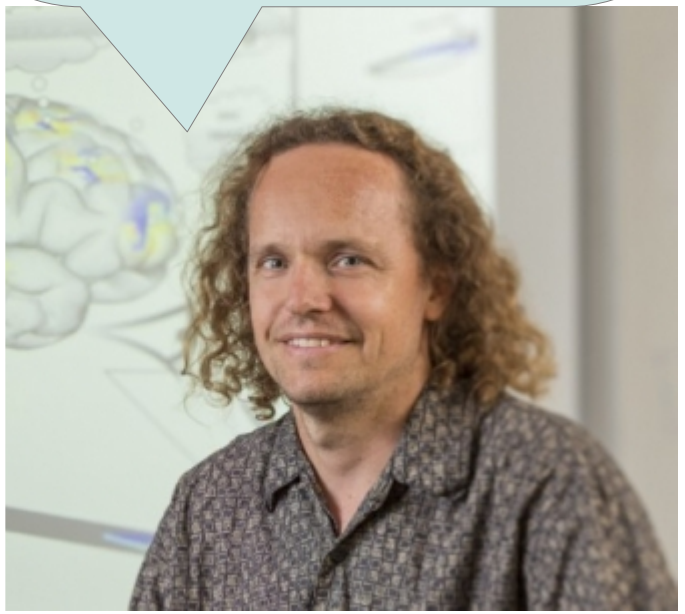
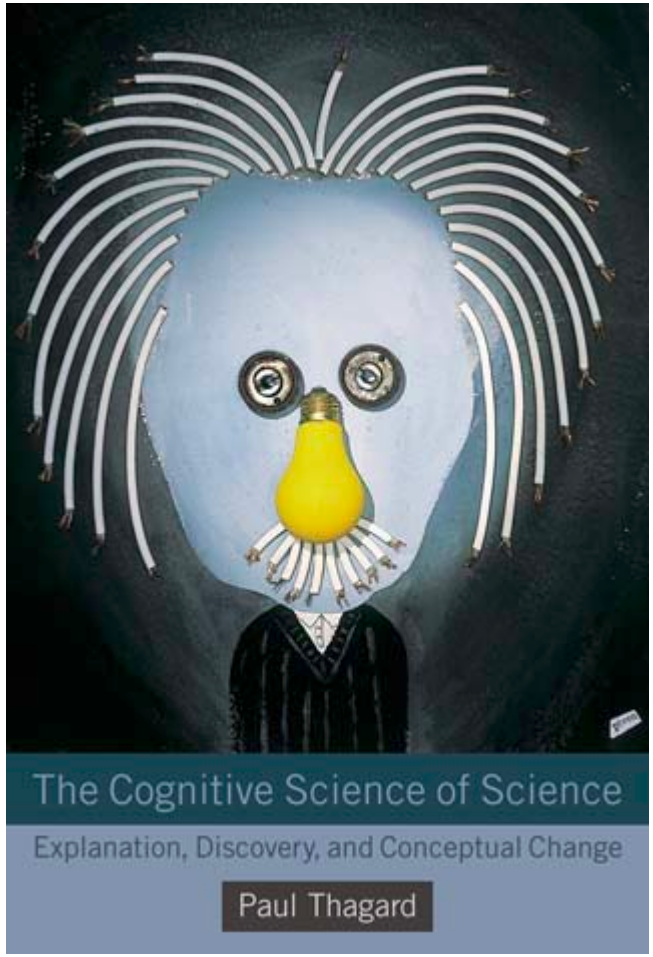
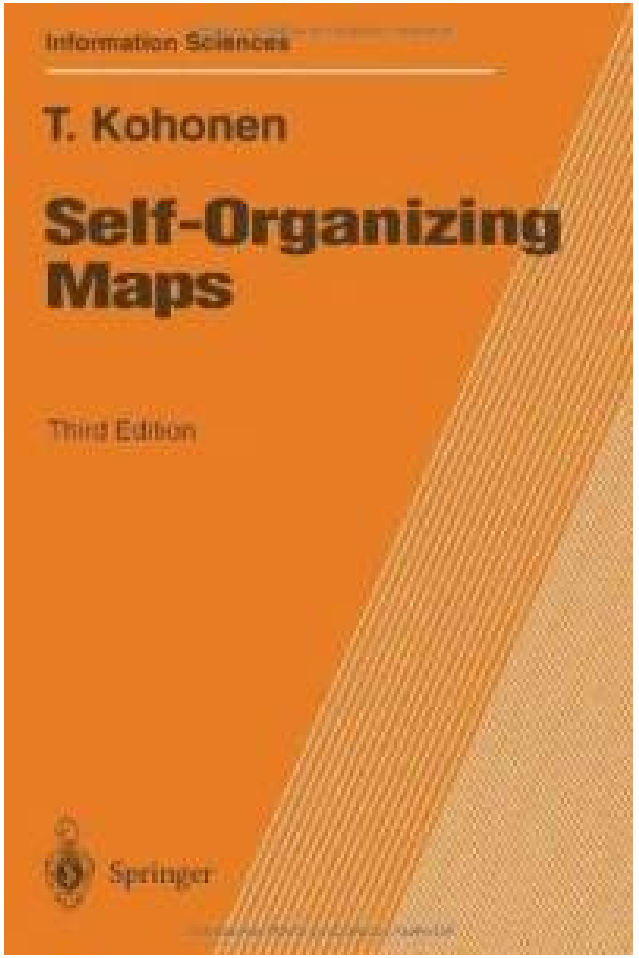


Chris Eliasmith:
How to build a brain:
A neural
architecture for
biological cognition
(Oxford, in press)



Suggested reading





Revival of connectionism

The European Commission has officially announced the selection of the Human Brain Project (HBP) as one of its two FET Flagship projects. The new project will federate European efforts to address one of the greatest challenges of modern science: understanding the human brain.

Review of

Computational and theoretical tools: UNDERSTANDING

Understanding

- One important aspect of understanding is related to the ability to build a link between perceptions of phenomena and categories/concepts
- This link can be traversed in two directions: (1) we associate perceptions with the names of the concepts, and (2) we can associate words that label concepts with prototypical instances of patterns of reality

Understanding

- Depending on the definition used, understanding and perception are closely related processes
- A full account on understanding should probably include also description of what happens after perception: how the perception leads into action and closes the perception-action loop
  - For these, probabilistic or information-theoretical framework may be considered useful
- There are also many other relevant themes for which there is not room to discuss here including top-down versus bottom-up processes

Review of

Computational and theoretical tools: CONFLICT

Conflict in perception

- In the perception process, a person may encounter a situation in which there is no appropriate “explanation” for the observed phenomenon – this situation can be called a conflict (cf. the diagram by Merenluoto & Lehtinen)
- From the computation modeling point of view, many kinds of remarks can be made on this matter

Modeling conflict processing

- An essential aspect is measuring similarities and differences: does the “input” match with the existing model within some acceptable range
- The methodology of assessing similarity depends heavily on the ontological assumptions and representational means being used

Modeling conflict processing

- Relevant methodological possibilities include:
  - Measuring distance in a vector space
  - Conducting graph comparison
  - Measuring edit distance of string representations
  - Estimating conditional probabilities of different contextual alternatives
  - Conducting analogical reasoning

Review of

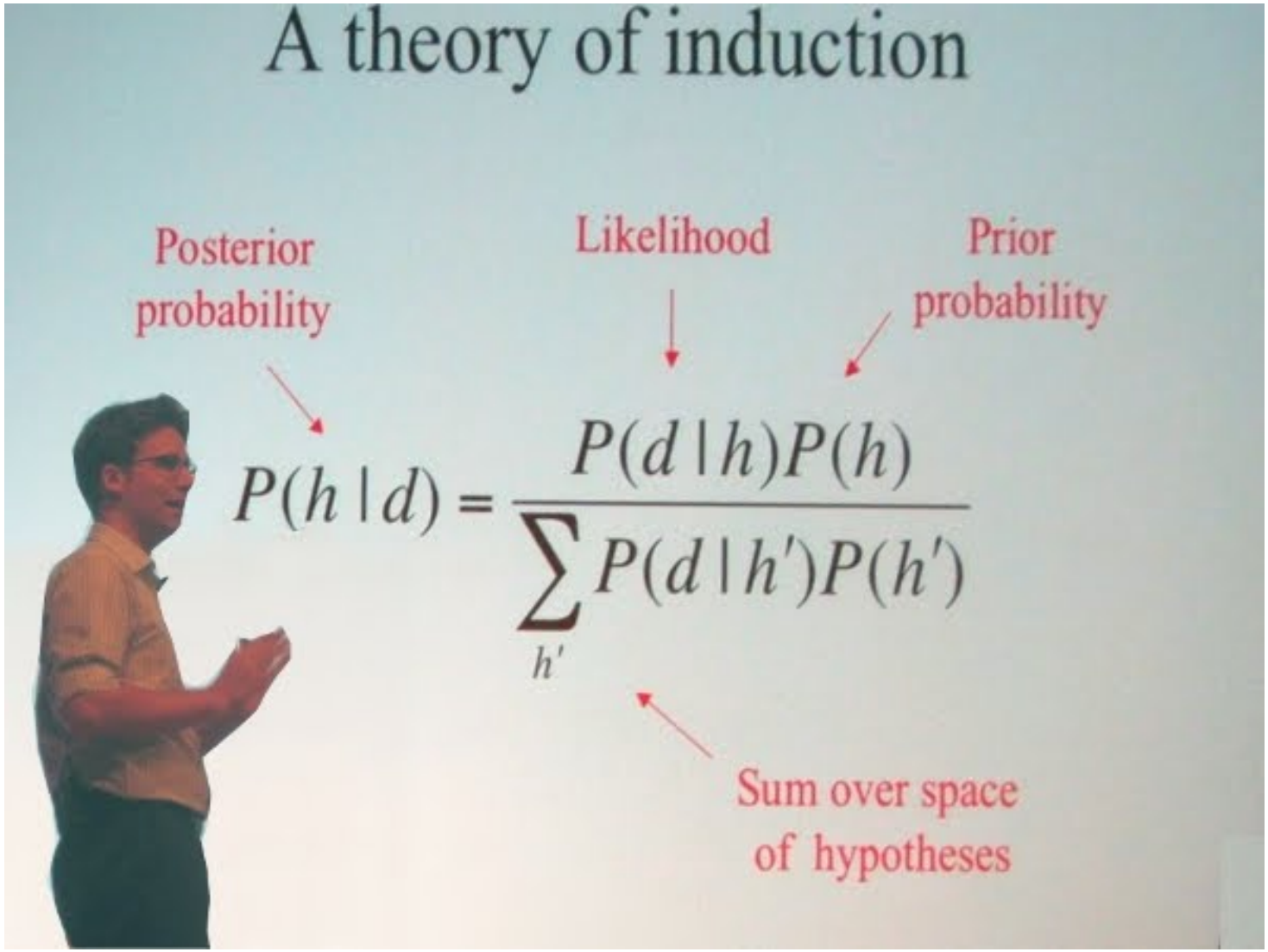
Computational and theoretical tools: CONCEPT LEARNING

Concept learning

- There is a wide range of different approaches that have been applied in order to computationally model concept learning
- Many of these approaches have been developed within the traditions of machine learning and neural network research
- Two approaches are considered here: Bayesian models and self-organizing maps

Bayesian modeling of concept learning

- "We observe *n* positive examples $X = \{x^{(1)},\ldots,x^{(n)}\}$ of concept *C* and want to compute the generalization function $p(y \in C|X)$, i.e. the probability that some new object *y* belongs to *C* given the observations *X*." (Tenenbaum, NIPS 1999)
- "[...] rules and similarity are best seen as two ends of a continuum of possible concept representations."
  "[...] each hypothesis *h* contributes to the average […] in proportion to its posterior probability $p(h|X)$, the degree of uncertainty in $p(h|X)$ determines whether generalization will be sharp or graded." (Tenenbaum, NIPS 2000)



Tom Griffiths, ICANN 2011, Espoo

Suggested reading

Cognition 114 (2010) 165–196

Contents lists available at ScienceDirect

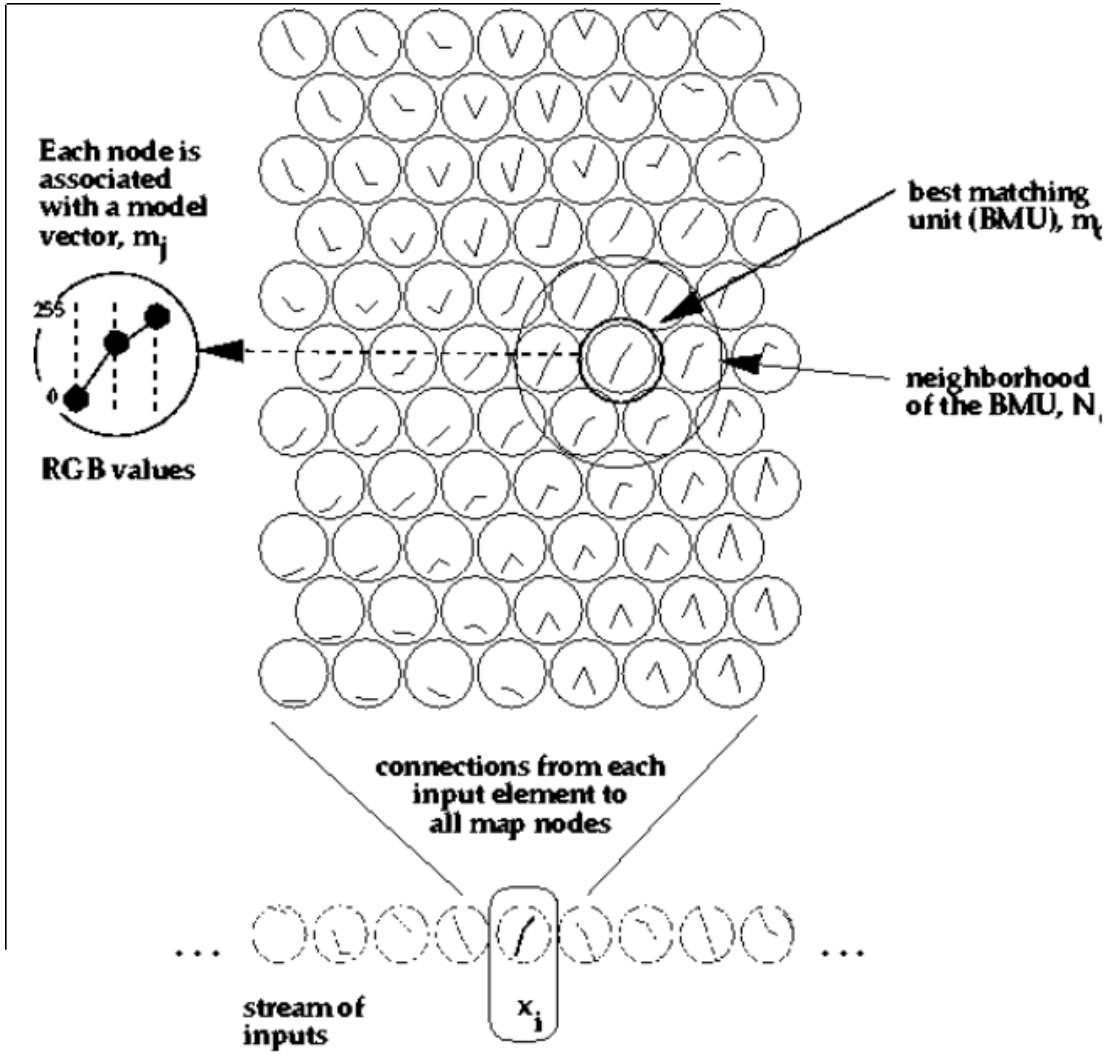
Cognition

journal homepage: www.elsevier.com/locate/COGNIT

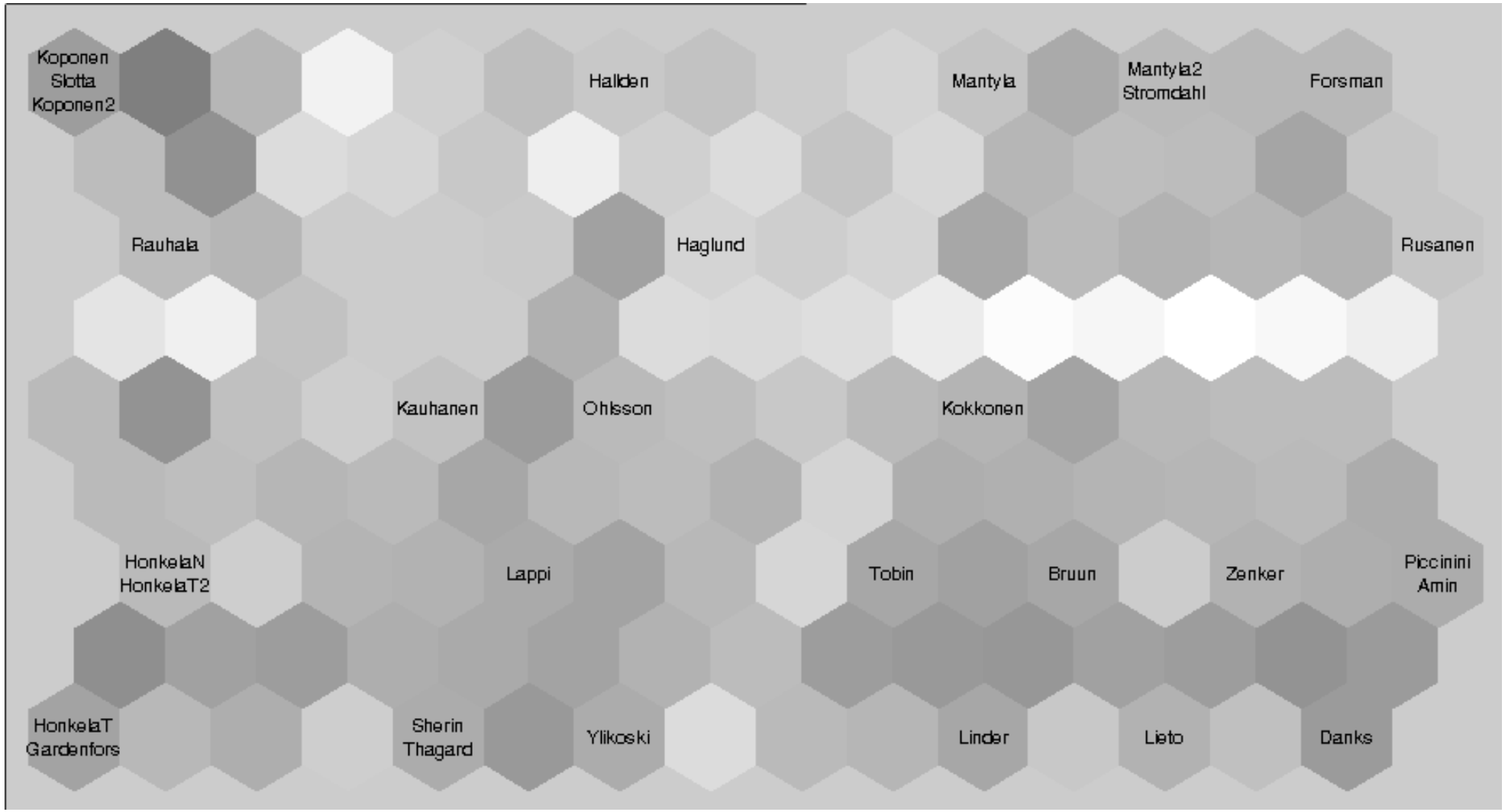
A probabilistic model of theory formation

Charles Kemp [a,*], Joshua B. Tenenbaum [b], Sourabh Niyogi [c], Thomas L. Griffiths [d]

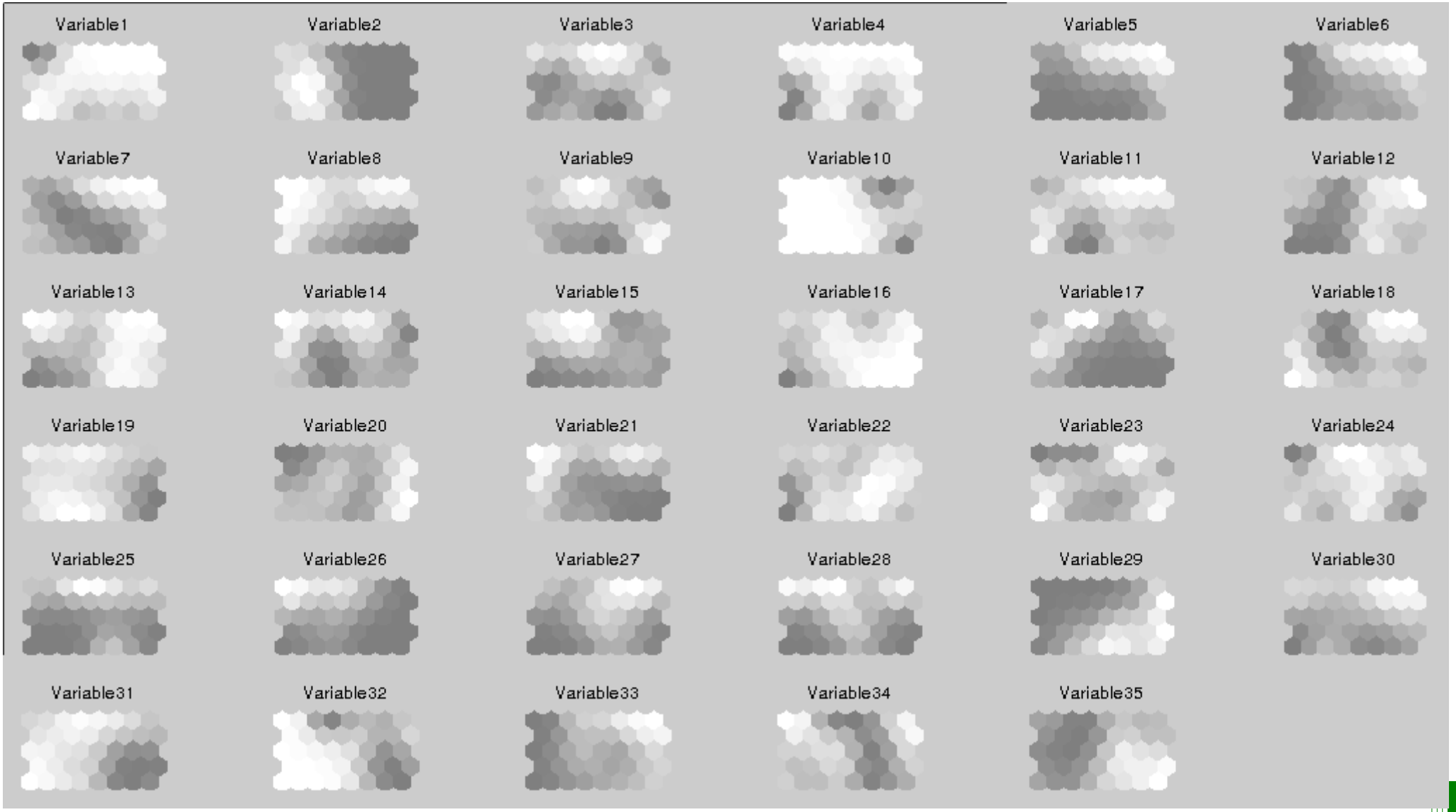
Concept learning using self-organizing maps



SOM of ConChaMo participants



Question distribution over the SOM



Remark on consciousness

- Thagard: “Consciousness as competition of semantic pointers”
- Kohonen: Competitive learning and winner-takes-all in the self-organizing map model (no claims on consciousness made earlier but a connection may exist)

Review of

Computational and theoretical tools: CONCEPTUAL CHANGE

Modeling conceptual change

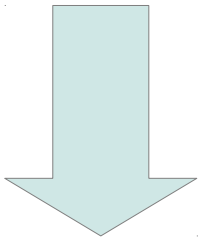
- Peter Gärdenfors will provide tomorrow an account on modeling conceptual change based on the conceptual change theory
- Potential alternative approaches include
  - Considering changes in topological structures in self-organizing maps
  - Applying catastrophe theory within the framework of dynamical systems theory

Computational and theoretical tools:
MODELING SUBJECTIVITY OF UNDERSTANDING

Meaning is subjective

Meaning is subjective

- Good
- Fair
- Useful
- Scientific
- Democratic
- Sustainable
- etc.

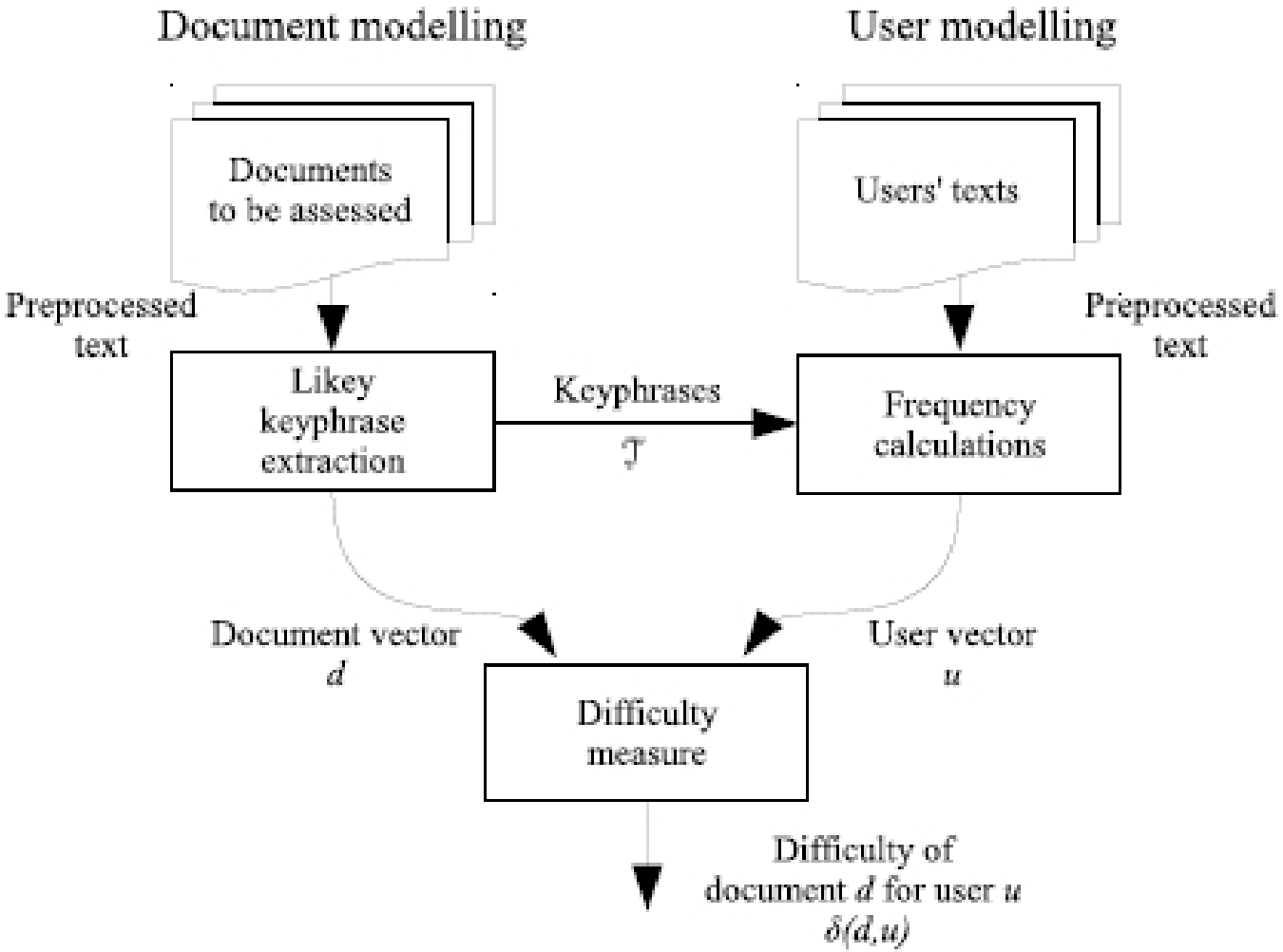


A proper theory of meaning has to take this into account

User-specific difficulty assessment

Basic architecture of the method

User-specific difficulty assessment



Paukkeri, Ollikainen & Honkela, Information Processing & Management, 2013.

GICA: Grounded Intersubjective Concept Analysis

Timo Honkela, Juha Raitio, Krista Lagus, Ilari T. Nieminen, Nina Honkela, and Mika Pantzar.

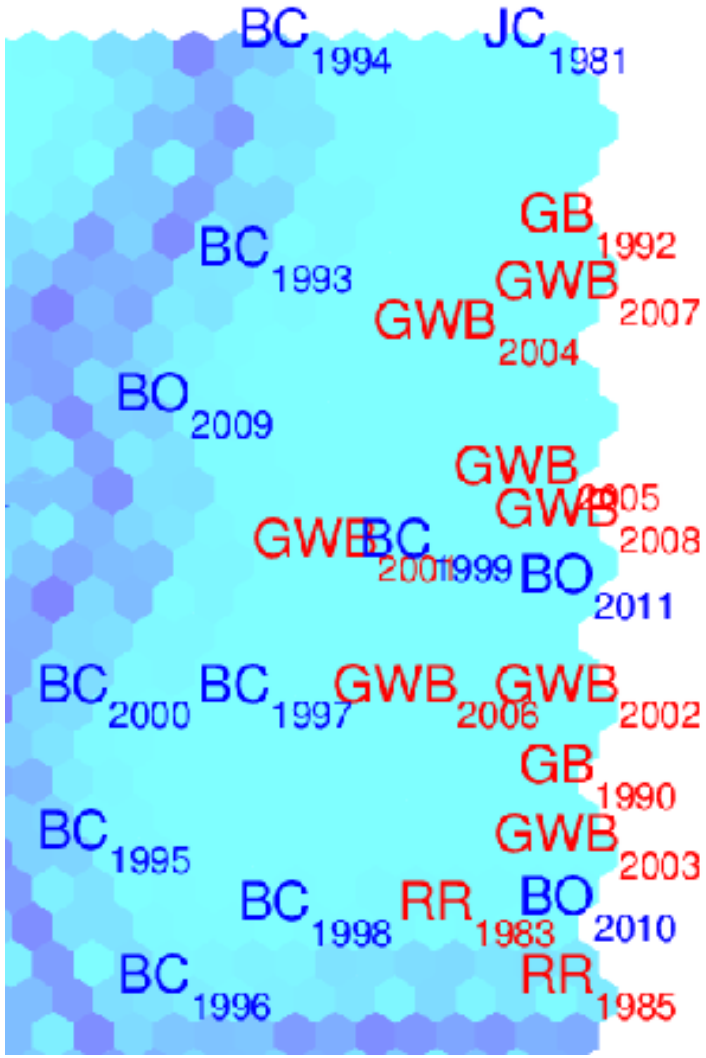
Subjects on objects in contexts: Using GICA method to quantify epistemological subjectivity.

Proceedings of IJCNN 2012, International Joint Conference on Neural Networks, pp. 2875-2883, 2012.

Case: State of the Union Addresses

- Text mining is used in populating a Subject-Object-Context tensor
- This took place by calculating the frequencies on how often a subject uses an object word in the context of a context word
  - Context window of 30 words

Analysis of the word 'health'

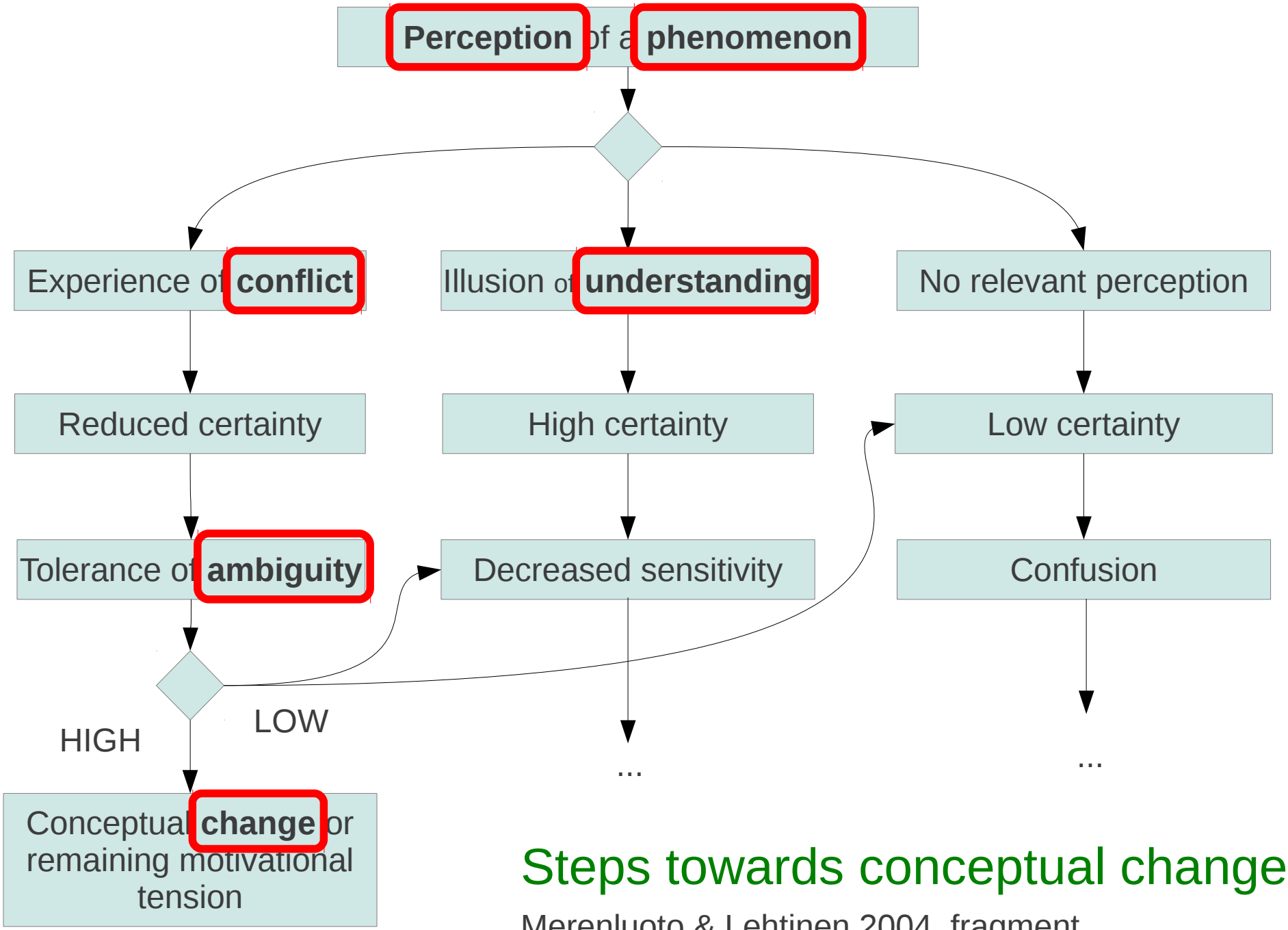


JC	Jimmy Carter
RR	Ronald Reagan
GB	George Bush
BC	Bill Clinton
GWB	George W. Bush
BO	Barack Obama

Conclusions

- Languages, including formal languages, should be considered as tools for coordination, storing and sharing knowledge in a compressed form – **approximate** and **relative** to the point of view taken
- Constructing a language or symbol system (such as an ontology) is an **investment** and spreading the language into use in a community is even a larger one

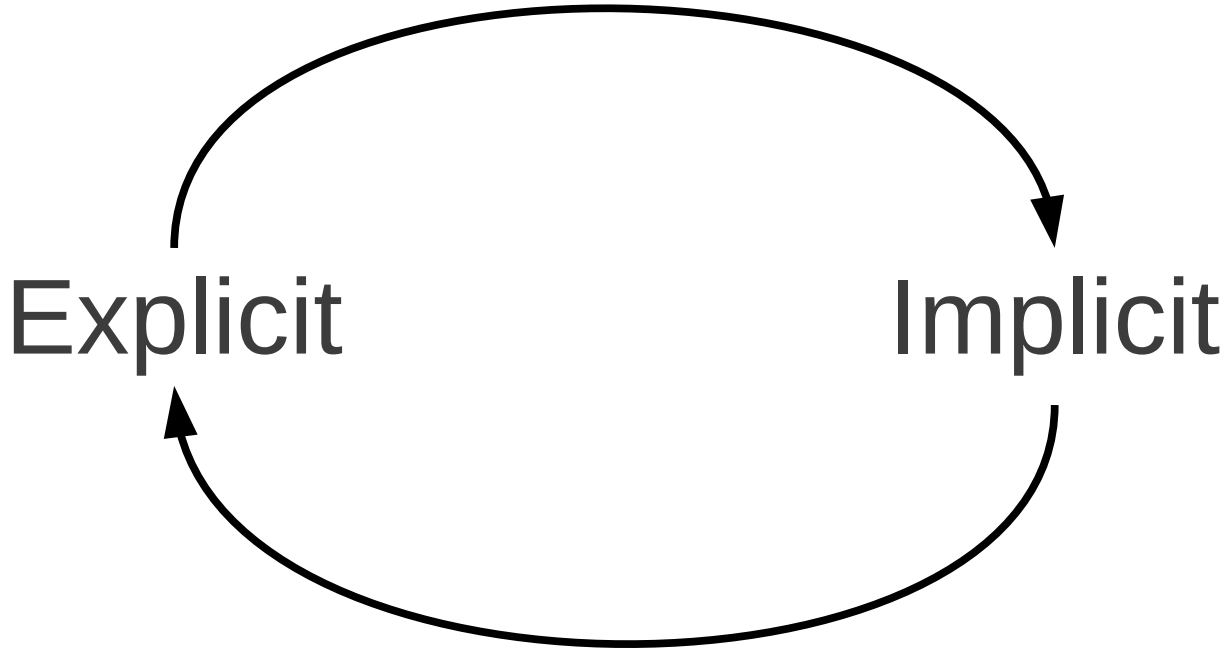
Timo Honkela, Ville Könönen, Tiina Lindh-Knuutila, and Mari-Sanna Paukkeri. **Simulating processes of concept formation and communication**. *Journal of Economic Methodology*, 15(3):245–259, 2008.



Steps towards conceptual change

Merenluoto & Lehtinen 2004, fragment

Vygotsky, Nonaka & Takeuchi



There are multiple relevant ways to assess conceptual change taking place among people

This is different from trying to understand the role and nature of the implicit and how transformations between explicit and implicit take place

Thank you! Merci!

Kiitos! ¡Gracias! Obrigado!

Danke schön! ありがとう