SPATIAL
COGNITION

Modularity and Abstraction in Natural Language Spatial Semantics:
searching for systematicity in the problem space

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ALBERT-LUDWIGS-
UNIVERSITÄT FREIBURG

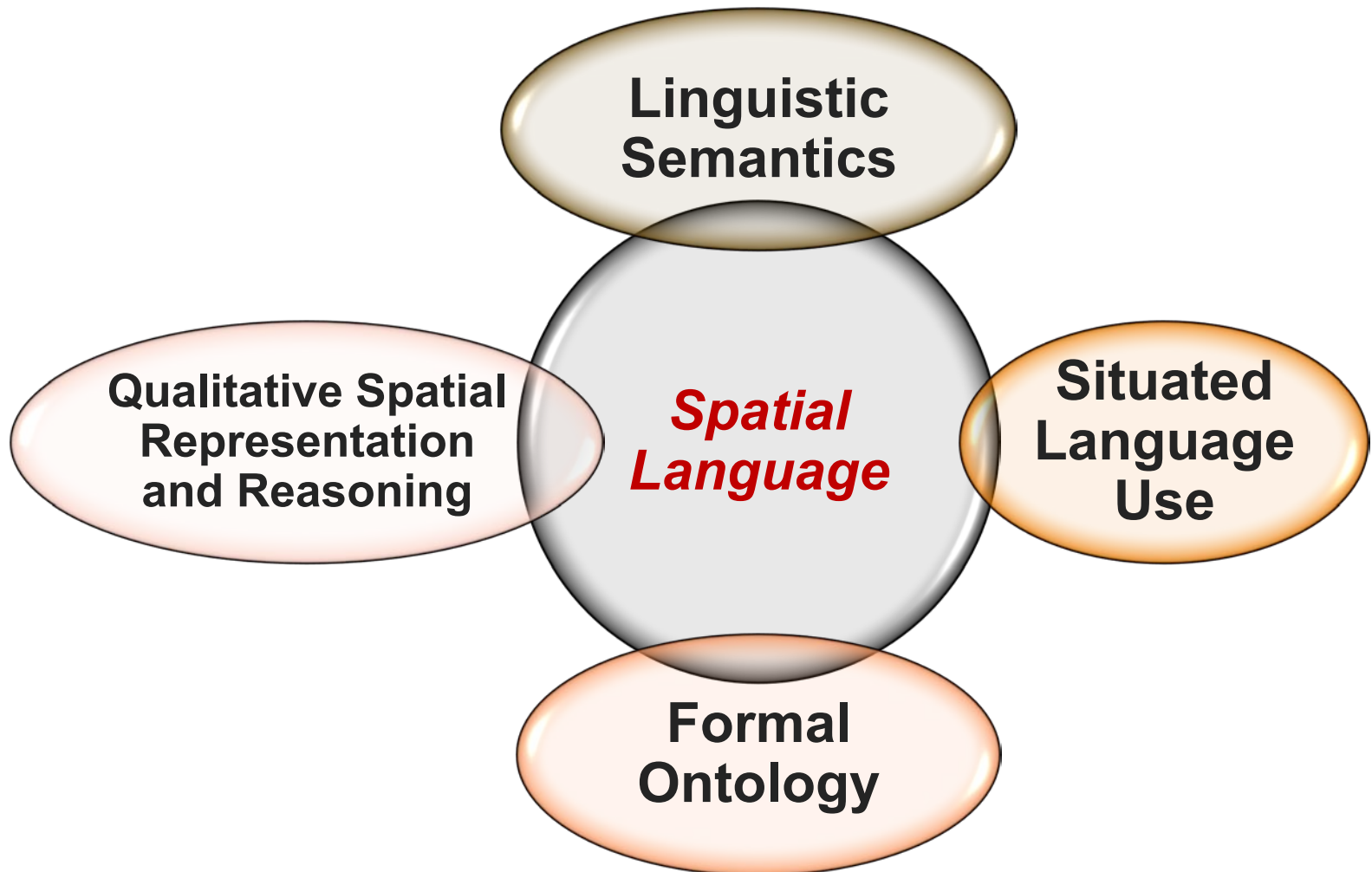# Many treatments of spatial language

- cognitive semantics

- spatial language and psycholinguistics

- QSR, ontology of space, formal semantics

- GIS, text-mining, robotics

- spatial language usage

Overview:
Bateman, J. A. (2010), 'Situating spatial language and the role of ontology: issues and outlook', *Linguistics and Language Compass.*

Sources of evidence and approaches

Linguistic Semantics

Qualitative Spatial Representation and Reasoning

Spatial Language

Situated Language Use

Formal Ontology

Focus and Outcomes

- Consequences for natural language semantics

- Consequences for linguistic annotation

- Consequences for methodologies and architectures

- Consequences for situated systems that communicate with people

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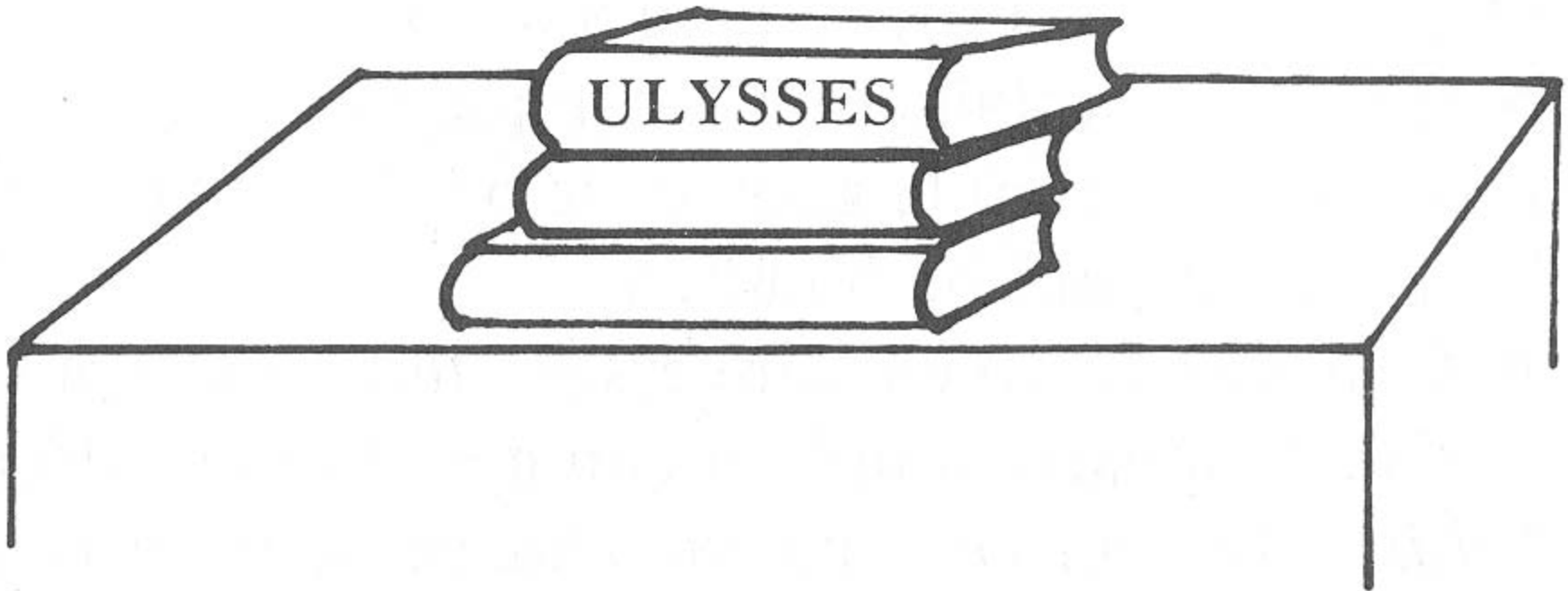
How to relate language and action – spatial action

- Problems with simple approaches
  - direct relations drawn between language and QSR / geometry / logic do not reflect flexibility of spatial language use
  - isolated examples do not reflect flexibility
  - corpus data (alone) do not reflect flexibility
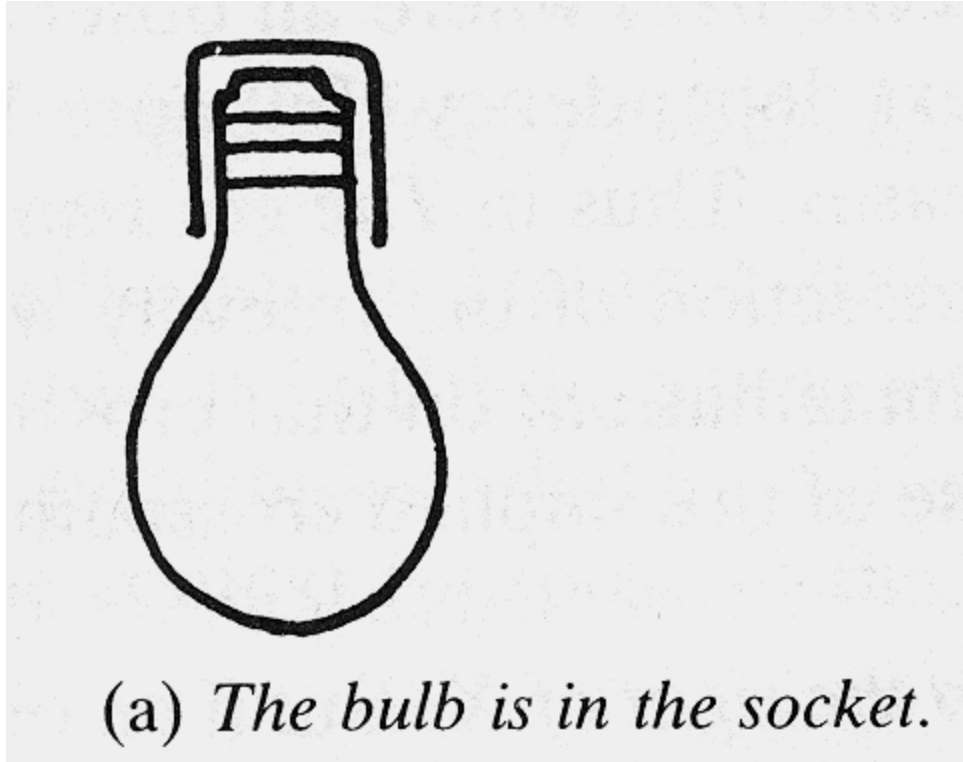
Usage evidence…

what does 'on' mean?

Herskovits (1986)

Usage evidence…

what does 'in' mean?

Herskovits (1986)

(a) *The bulb is in the socket.*

Functional effects

Coventry, Garrod and others

Requirements

OntoSpace/DiaSpace

- to capture the spatial commitments of spatial language at an appropriate level of abstraction

- to relate those commitments to spatial situation descriptions

- to provide an organising framework for spatial language constructions

Considerable problems caused by 'over committing' to what is linguistically present
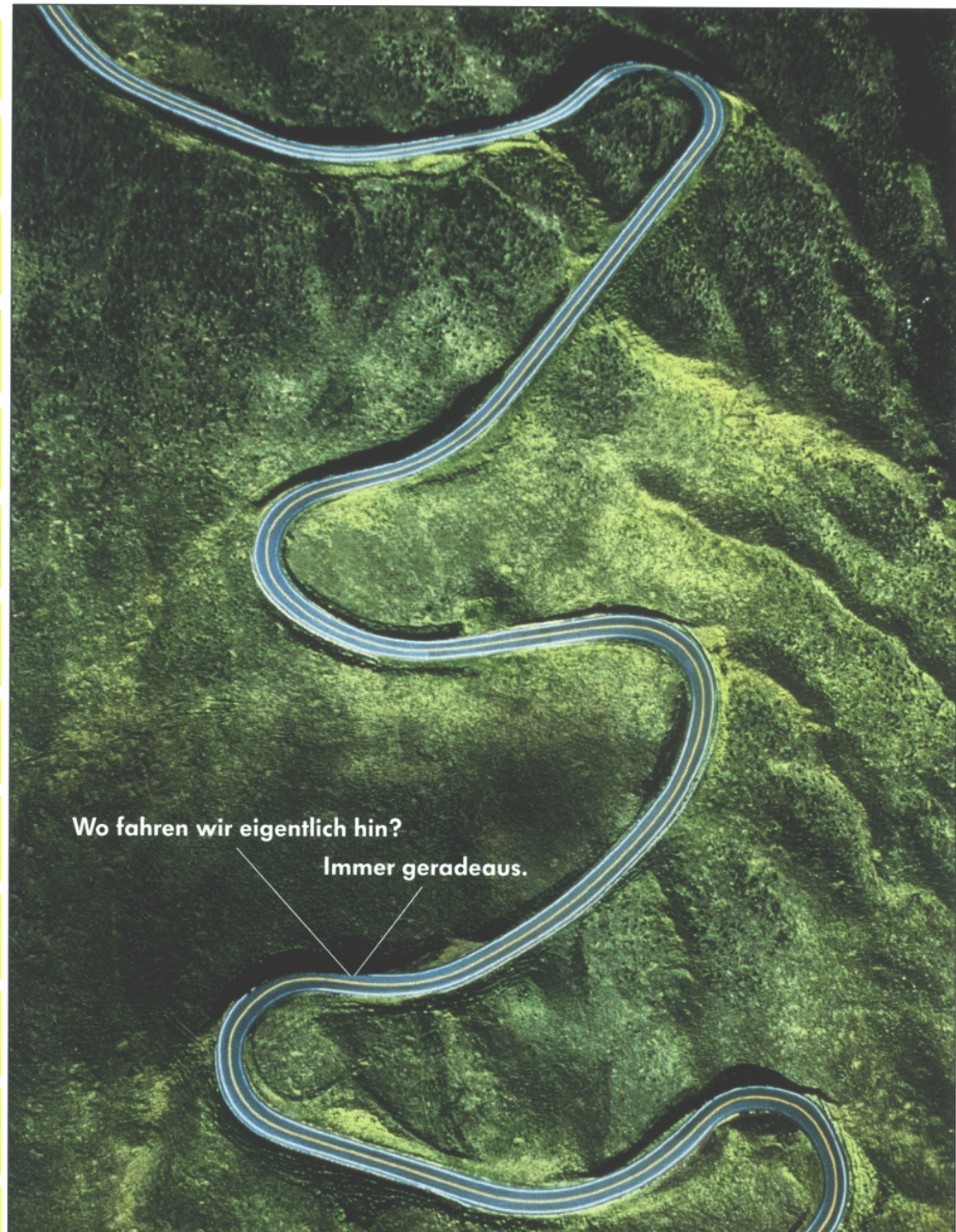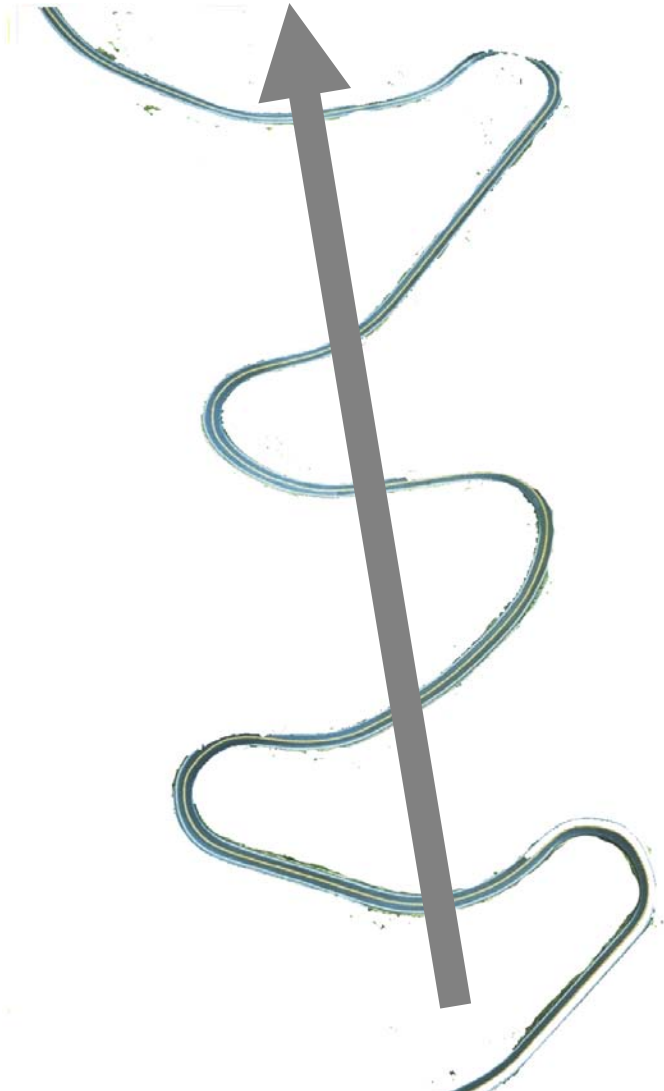
- **Goal:**
  to determine the minimal commitments of any particular linguistic expression

  - e.g., Bateman/Hois/Ross/Tenbrink (2010)
    A linguistic ontology of space for natural language processing.
    Artificial Intelligence, 174(14):1027–1071.

    which gives me an excuse to use my favourite slide ! ☺

Schematization

Wo fahren wir eigentlich hin?

Immer geradeaus.

How to relate language and action – spatial action

- Our approach:
  - examine the diversity of language use in related to concrete situations of language use and communicative goals
  - e.g., situated robotic autonomous agents

- Model & Architecture
  - spatial language: functional, nongeometric
  - two-level semantics
  - linguistic ontology

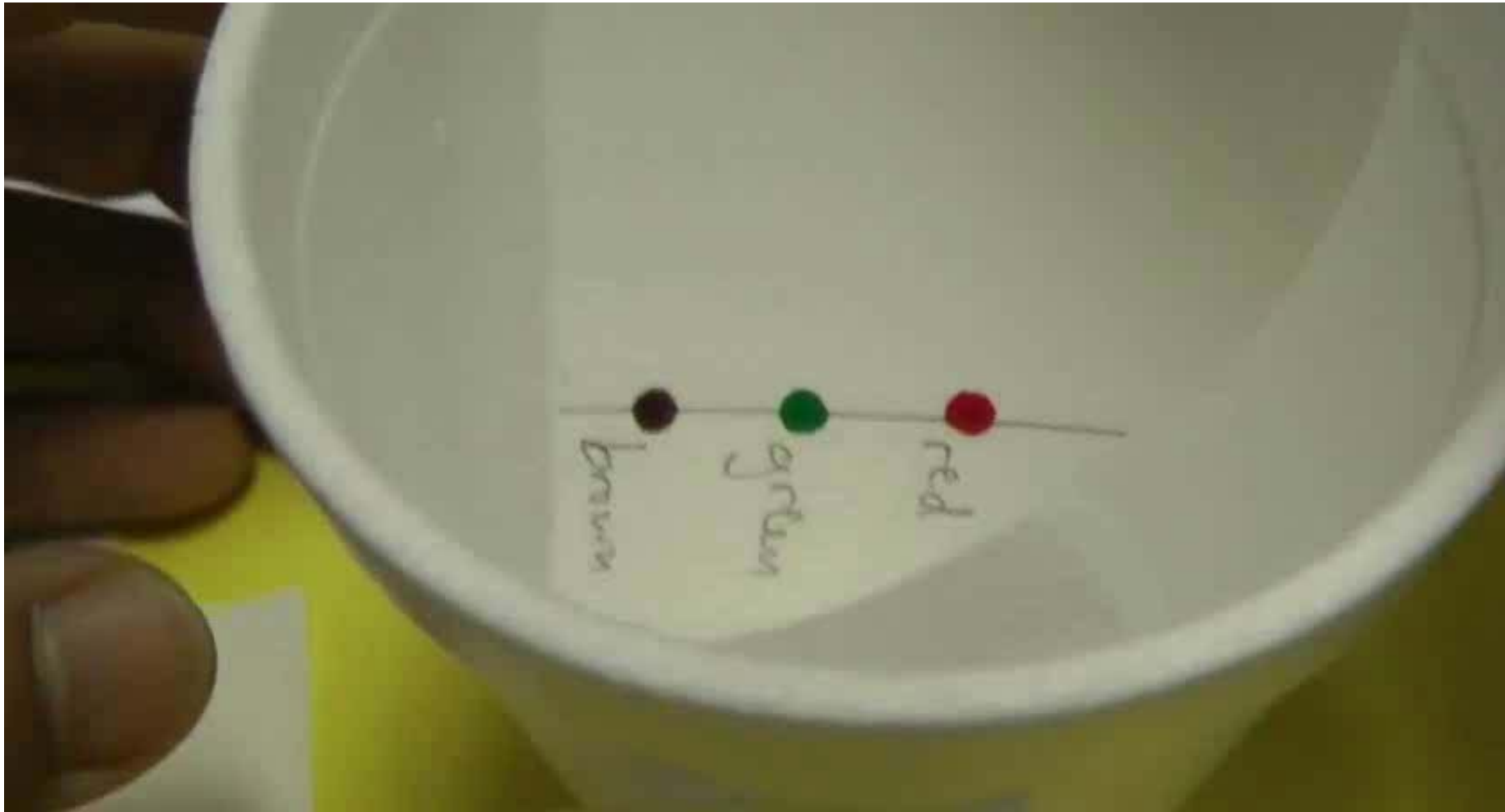# How to relate language and action – spatial action

- Methodology for design of linguistic ontology
  - grammar / constructions / paradigmatic: look at **grammar** not lexemes
  - functional: look at what utterances **do**
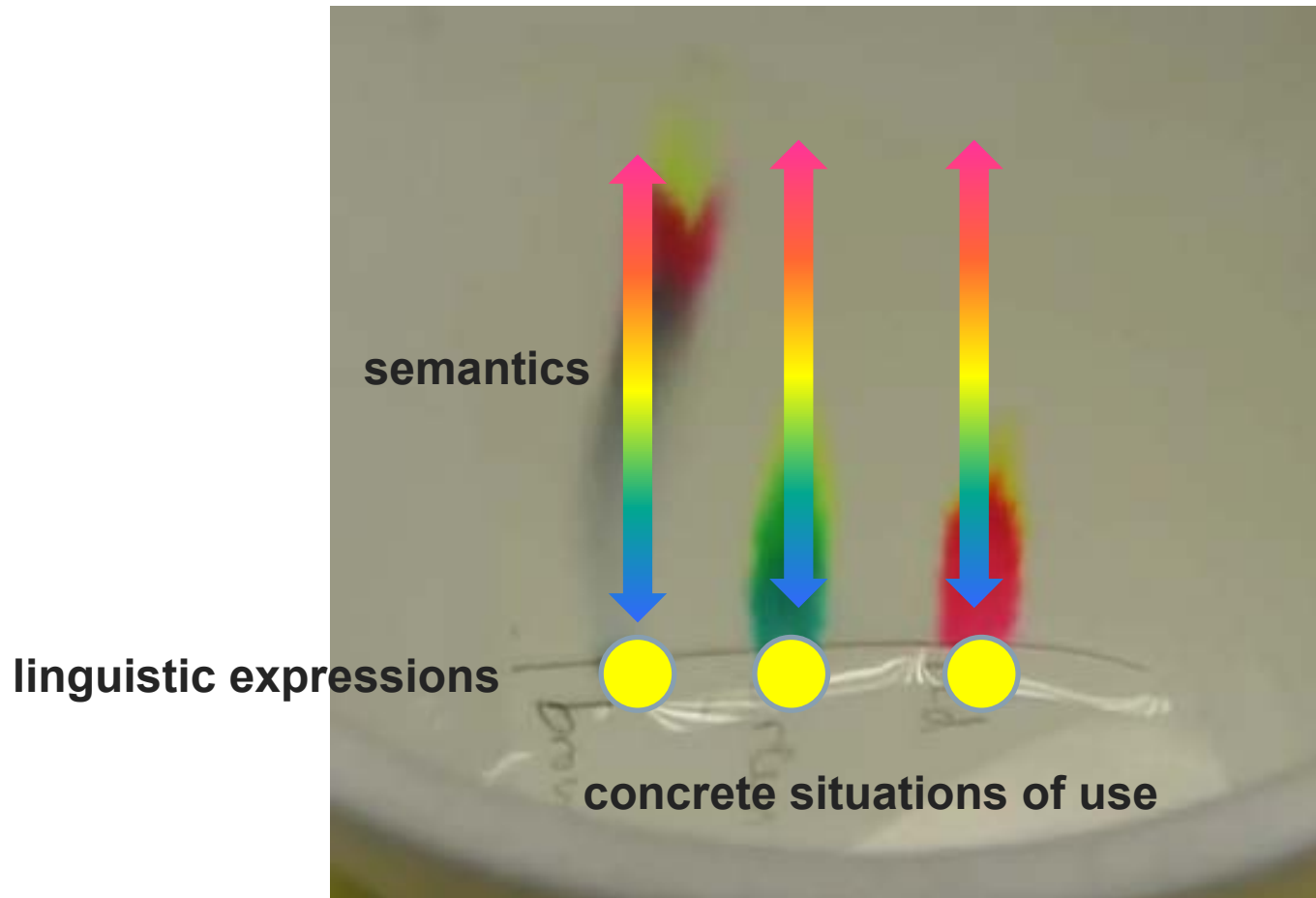 - semantics configurations select for diverse paradigmatic options across the grammar

Do not ask what 'on' means, rather ask what is achieved in context by a grammatical structure using 'on'

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Method: An analogy ...

Method: An analogy ...

semantics

linguistic expressions

concrete situations of use

https://www.youtube.com/watch?v=8Sq8k4_YYTQ [guayhansen]

Building on the Development of the 'Penman Upper Model'

OntoSpace/DiaSpace

A linguistically motivated ontology for driving natural language generation (USC/ISI, 1985-89)

Similar ontologies adopted in variety of NLG systems

- event-based
- induced from **grammatical patterns**, not lexical
- language-specific *unless similar grammatical patterns occur in differing languages*
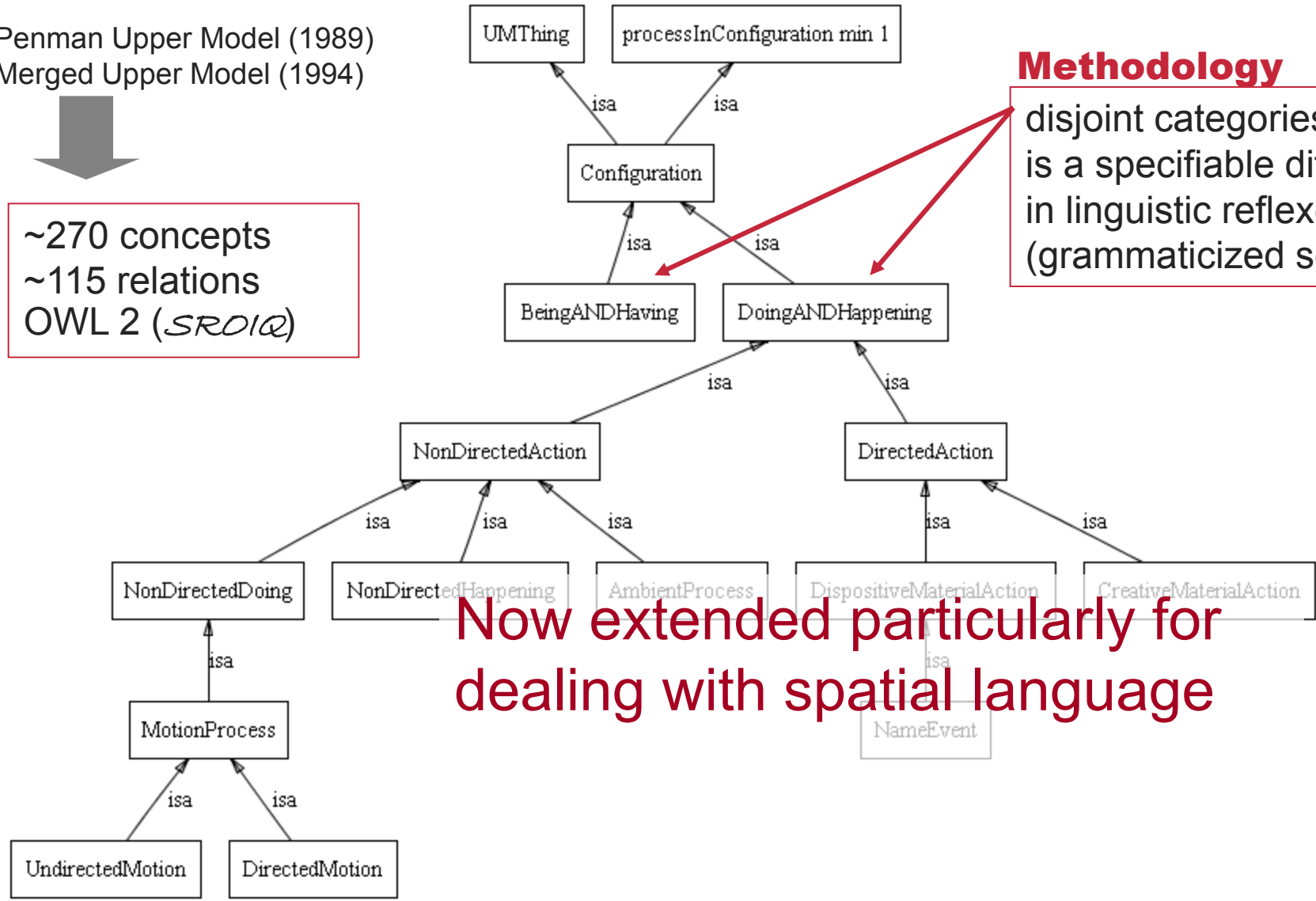
Generalized Upper Model : Version 3
(2004-2012)

Metadata | OWLClasses | Properties | Individuals | Forms | Ontoviz

Penman Upper Model (1989)
Merged Upper Model (1994)

~270 concepts
~115 relations
OWL 2 ($\mathcal{SROIQ}$)

Methodology

disjoint categories iff there is a specifiable difference in linguistic reflexes (grammaticized semantics)

UMThing

processInConfiguration min 1

isa   isa

Configuration

isa   isa

BeingANDHaving   DoingANDHappening

isa

NonDirectedAction   DirectedAction

isa   isa   isa   isa   isa

NonDirectedDoing   NonDirectedHappening   AmbientProcess   DispositiveMaterialAction   CreativeMaterialAction

isa   isa

MotionProcess   NameEvent

isa   isa

UndirectedMotion   DirectedMotion

Now extended particularly for dealing with spatial language

Google
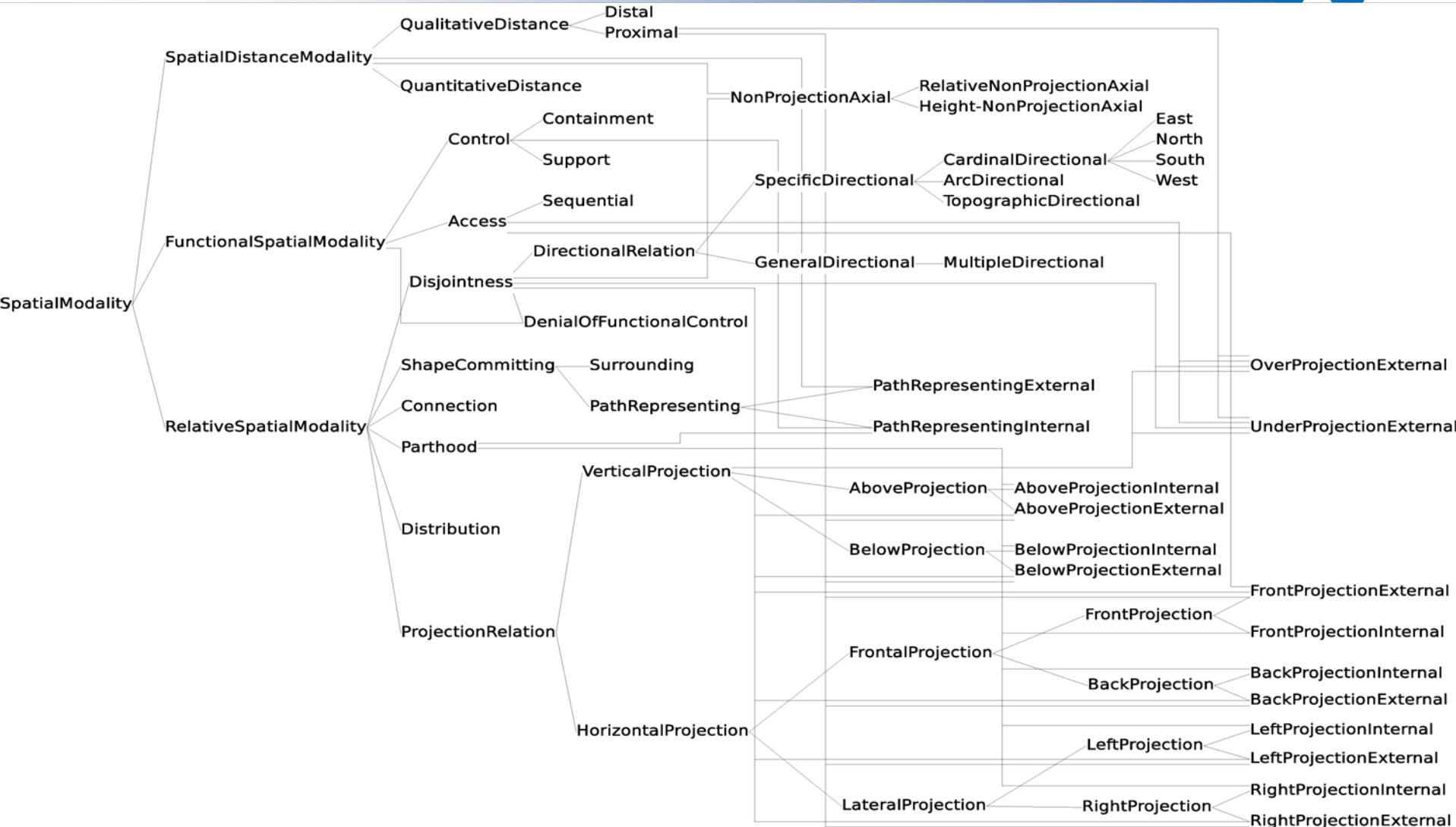
Grouping of spatial relations expressed linguistically

Category / Implications	Projective (left, right, above, below, front, back... links, rechts...)	Functional Control internal: in	internal: inside	external: on, an	external: auf	Path representing internal: across, through, entlang, durch...	external: along, entlang, längs...	Directional specific cardinal: East, North, östlich, Osten...	specific topographic: uphill, bergauf...	general: (-)to, -ward, from... von, nach, zu...hin, -wärts	non-oriented: near, far, nahe, weit...	non-oriented: at, bei	oriented: opposite, gegenüber	oriented: facing	Distribution: among, between, inmitten, zwischen...	Nonprojective axial: beside, at the side of, next to... neben...	Surrounding: around... (um) herum...
Shape committing						x	x										x
Axis or direction assigning	acc. to term				vertical			x	x							(lateral)[1]	
Refsys involved	x				x[2]											(x)	
Requiring a relatum (simple or complex)	x	x	x	x	x	x	x				x	x	x	x		x	x
Requiring complex relatum															x		
Perceptual accessibility / Potential reach/ interaction	(x)											x		x		x	x
Functional containment		x															
Functional support				x													
Distance assigning	(proximity as default)						proximity as default				x	x	some distance	proximity as default			
Coincidence (at least overlap)		x				x						(x)			(x)		
Strong coincidence required	(x)		x									(x)					
Contact	(x)			x	x		(x)					(x)				(x)	(x)
Disjunct	(x)						(x)	x	x	x	x	(x)	x	x	(x)	x	(x)
Orientation of locatum required													x	x			
Orientation of relatum required	(x)				x												

Tenbrink (2005, 2006)

Generalized Upper Model
Spatial Modalities

http://www.ontospace.uni-bremen.de

OK, go towards the mountains along the main road

until you reach a large wooden house.

Be careful, the road gets a bit narrow where the old church sticks out.

Turn right at the house and,

then, at the third intersection, turn right leaving the city limits.

Then turn downhill towards the river.

At the river, take the ferry over to the café.

DirectedMotion (
    direction:
        GeneralDirectional(*mountains*),
    route: GR (pathPlacement:
                PathRepresentingExternal
                    (*main-road*))
[*until*]
DirectedMotion (
    route GR (destination:
            GeneralDirectional (*house*))

CCG

SFG

Why this level of representation?

- We are seeking to describe what the **linguistic** contribution to spatial descriptions is

- One common failing is to mix this with contextualised interpretations **too early**.

How to explain the understanding of texts involving spatial information?

- One approach:
  formal modeling of the 'semantics'
  - but what is that semantics and
    how would we know?

- Ernest Davis
  (*Spatial Cognition and Computation*, forthcoming)
  keynote speech at the COSIT 2011

  addresses this question by drawing on several
  'narrative' texts, asking what spatial information would
  be required to 'understand' them

Davis (*SCC*, forthcoming)

- "Simple natural language texts and narratives often raise problems in commonsense spatial knowledge and reasoning of surprising logical complexity and geometric richness. In this paper, I consider a dozen short texts—five taken from literature, the remainder contrived as illustrations — and discuss the spatial reasoning involved in understanding them."

- a 'no holds barred' AI approach

Davis (*SCC*, forthcoming)

- "though textual understanding generates interesting individual problems, they are very haphazard in form. It does not generate any systematic class of problems. For both the theory and practice of computer science, this is very problematic."

Some of the example problems

- ## The Winograd schema (Levesque)

  *The city councilmen refused the demonstrators a permit because **they** [feared/advocated] violence.*

  - resolution of the anaphor requires *world knowledge* and must be performed abductively in context

  - neither the syntactic form nor semantic restrictions provide an answer

Davis: spatial examples of Winograd schemas

- The trophy would not fit into the brown suitcase because it was too [small/large].

  ❖ The trophy would not fit because it [= **the trophy**] was too **large**
  ❖ The trophy would not fit because it [= the **suitcase**] was too **small**

Davis' formalisations...

1. This trophy does not fit inside the suitcase, and no larger trophy fits inside the suitcase, but some smaller trophy does fit inside the suitcase.

2. The trophy does not fit inside this suitcase or inside any smaller suitcase but it does fit inside some larger suitcase.

(2.1) ¬FitsIn(Trophy,Suitcase) ∧
      [∀$_t$ Larger(ShapeOf(t),ShapeOf(Trophy)) ⇒ ¬FitsIn(t,Suitcase)] ∧
      [∃$_t$ Larger(ShapeOf(Trophy),ShapeOf(t)) ∧ FitsIn(t,Suitcase).]

(2.2) ¬FitsIn(Trophy,Suitcase) ∧
      [∀$_s$ Smaller(s,Suitcase) ⇒ ¬FitsIn(Trophy,s)] ∧
      [∃$_s$ Smaller(Suitcase,s) ∧ FitsIn(Trophy,s).]

Davis' formalisations...

"α cannot ϕ because it is too θ"

$$\neg\phi(\alpha) \wedge$$
$$[\forall_a \; \Theta(a, \alpha) \Rightarrow \neg\phi(a)] \wedge$$
$$[\exists_a \; \Theta(\alpha, a) \wedge \phi(a)]$$

ϕ is the property at issue, e.g., 'fitting'

Θ is a comparator, e.g., X is 'larger than' Y

Complications...

- the shape of the trophy and the space left in the suitcase (perhaps it is already partially packed)
  - 'fits in' is defined as involving some feasible shape

- *and:* how to define 'smaller' / 'larger'?

2.6a. $\text{Smaller(a,b)} \equiv \text{VolumeOf(a)} < \text{VolumeOf(b)}$.

2.6b. $\text{Smaller(a,b)} \equiv \text{DiameterOf(a)} < \text{DiameterOf(b)}$.

2.6c. $\text{Smaller(a,b)} \equiv a \subset b$.

2.6d. $\text{Smaller(a,b)} \equiv \exists_s \ s > 1 \land b = \text{Scale(a,s)}$.

  - all are held to be problematic...
    but suggests (d) comes off best...

Davis' moral from the story

The reader may reasonably object that the above discussion of the "correct" geometrical interpretations of "small" and "large" are misguided, as it is altogether unlikely that the speaker of this sentence had *any* well-defined geometric interpretation in mind, or even a well-defined logical formulation of "because it is too [small/large]." This objection, which is of course just one instance of the eternal misfit of language and logic, is certainly correct, but it seems to me that it only makes the problem more difficult. I believe that, in most cases, it is easier to work with a geometrically specific notion of "smaller" and "larger" than to try to characterize inference based on a geometrically indeterminate notion; and I certainly have no idea how one can analyze inferences based on logically indeterminate formulations.

BUT → what is haphazard is not textual understanding but the modeling of the semantics proposed...

Methodological Issue

"I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail."

Abraham H. Maslow (1962)
Toward a Psychology of Being

Abraham Kaplan (1964)
The Conduct of Inquiry: Methodology for Behavioral Science
p. 28.

So...
back to suitcases and trophies...

$$\text{``}\alpha \text{ cannot } \phi \text{ because it is too } \theta\text{''}$$

what is the minimal commitment that this construction makes?

Proposal.
that commitment is spatial but abstract

Proposal

$$\text{``}\alpha \text{ cannot } \phi \text{ because it is too } \theta\text{''}$$

ql_t

α

θ

Θ

not O.K.*

O.K.*
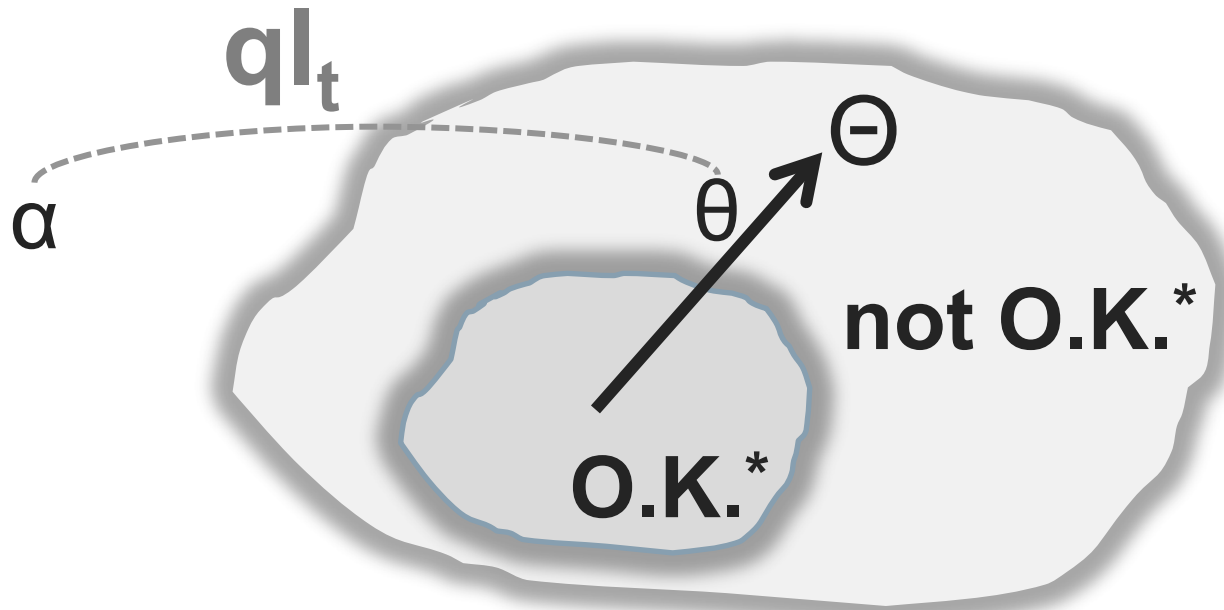
for ϕ-ing

Ontological commitments:
time-dependent qualities, evaluated quality spaces (DOLCE)
the judgment involved is a *functional* judgment

trophy cannot fit in suitcase
because trophy is too large

ql_t

trophy

θ

size

not O.K.

O.K.

trophy cannot fit in suitcase
because suitcase is too small

ql_t

suitcase

O.K.

θ

size

**not
O.K.**
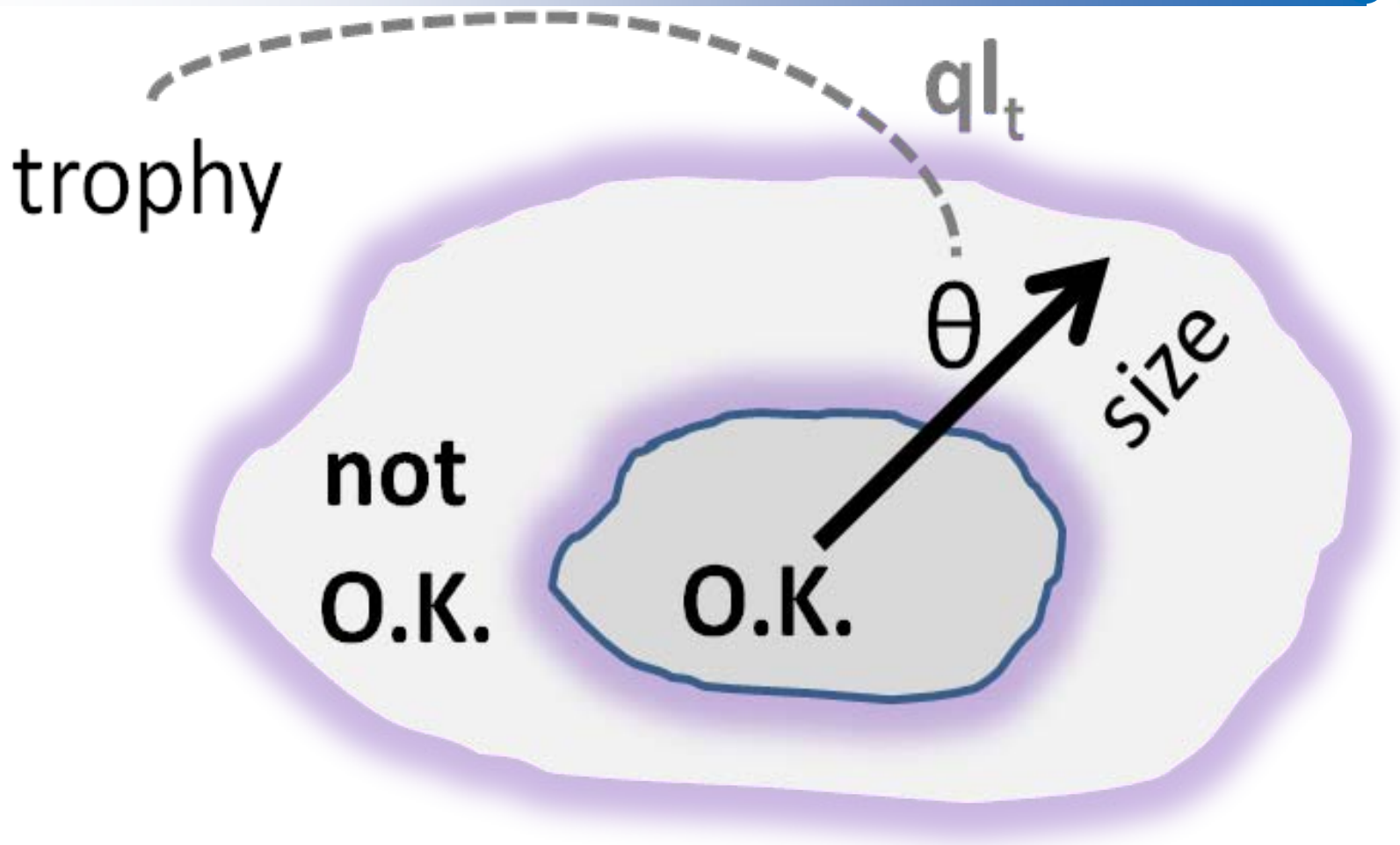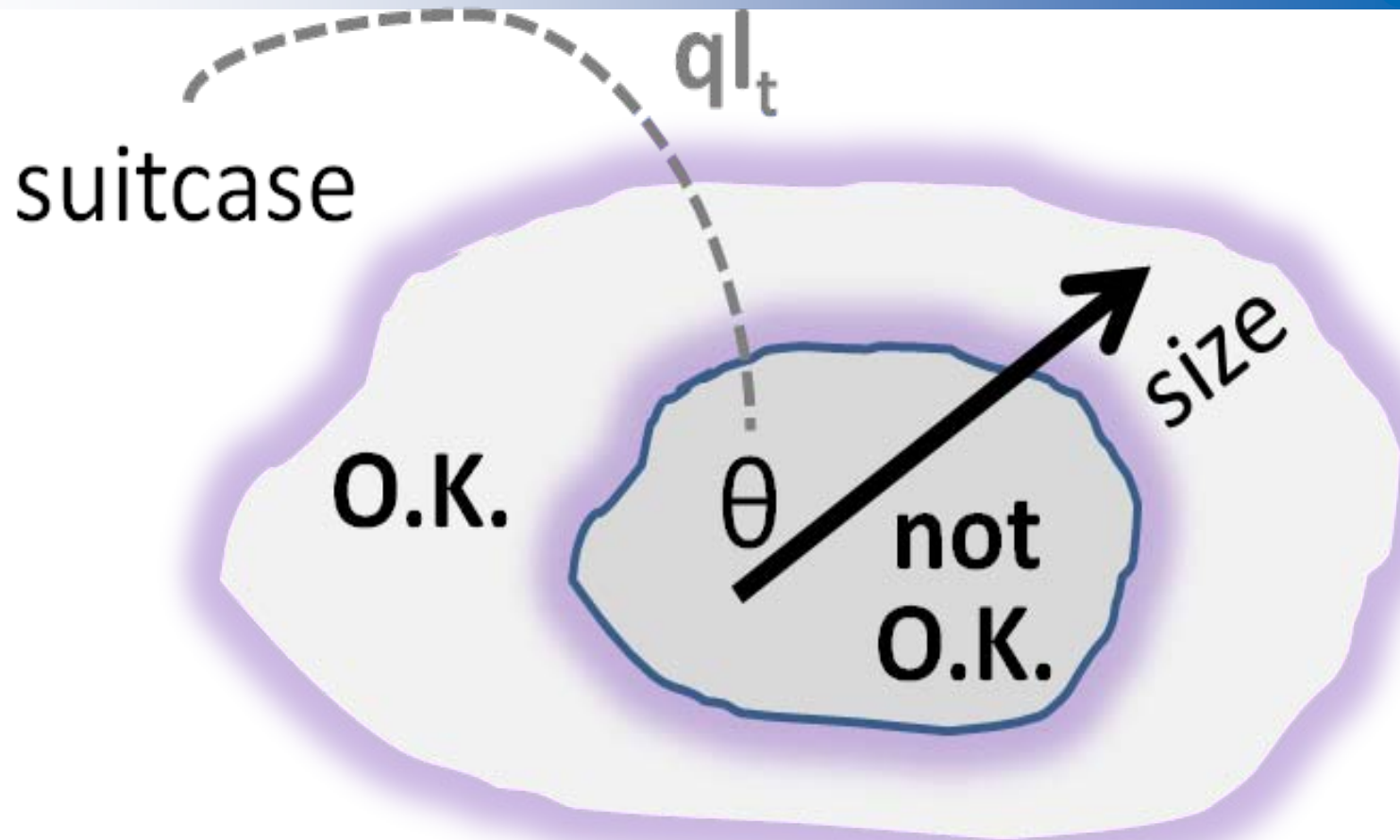
suitcase too large vs. trophy too small

trophy cannot fit in suitcase
because suitcase is too large

trophy cannot fit in suitcase
because trophy is too small

suitcase

ql_t

θ

size

not O.K. **O.K.**

trophy

ql_t

O.K.

θ **not O.K.**

size
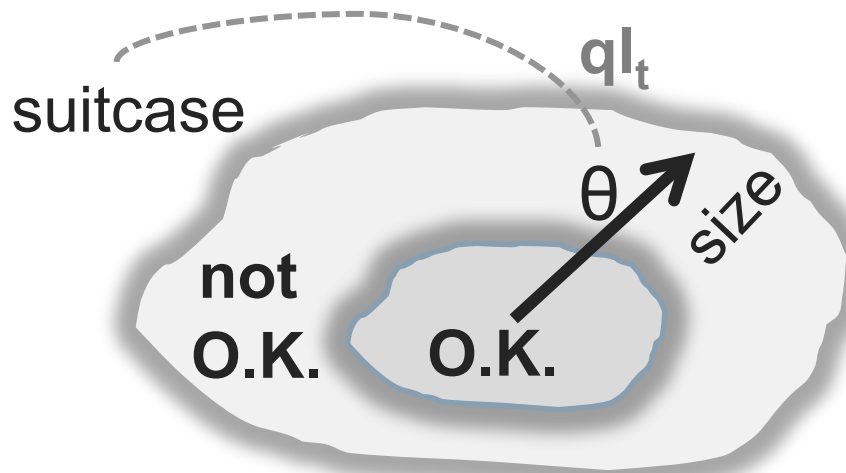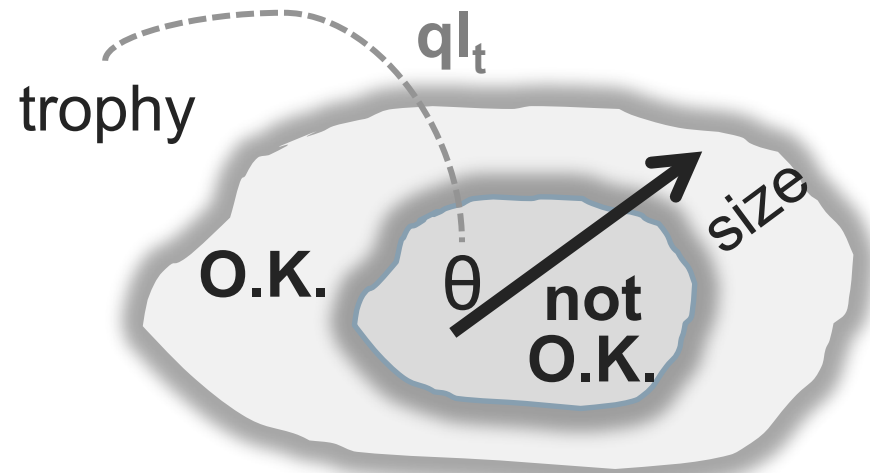
What does this buy us?

- A clear *modularisation* and demarcation of information that is part of the semantics of linguistic expressions and information which is not

- Analogies to formalisations which hide or package components to reduce complexity (e.g., SDRS and logics of discourse update, etc.)

- The ability to consider *alternative* further formalisations of the distinct levels of information

- *Openness* towards further specification: spatial calculi, embodied simulation, diagrammatic reasoning, mental models, axiomatisation à la Davis, situation semantics, …

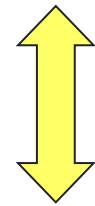- Abstracts away from geometric concerns
  just as language appears to do

Semantic Modularity

- **linguistic semantics**
  - (all and) **only** the commitments licensed by the linguistic constructions employed

- **contextualised semantics**
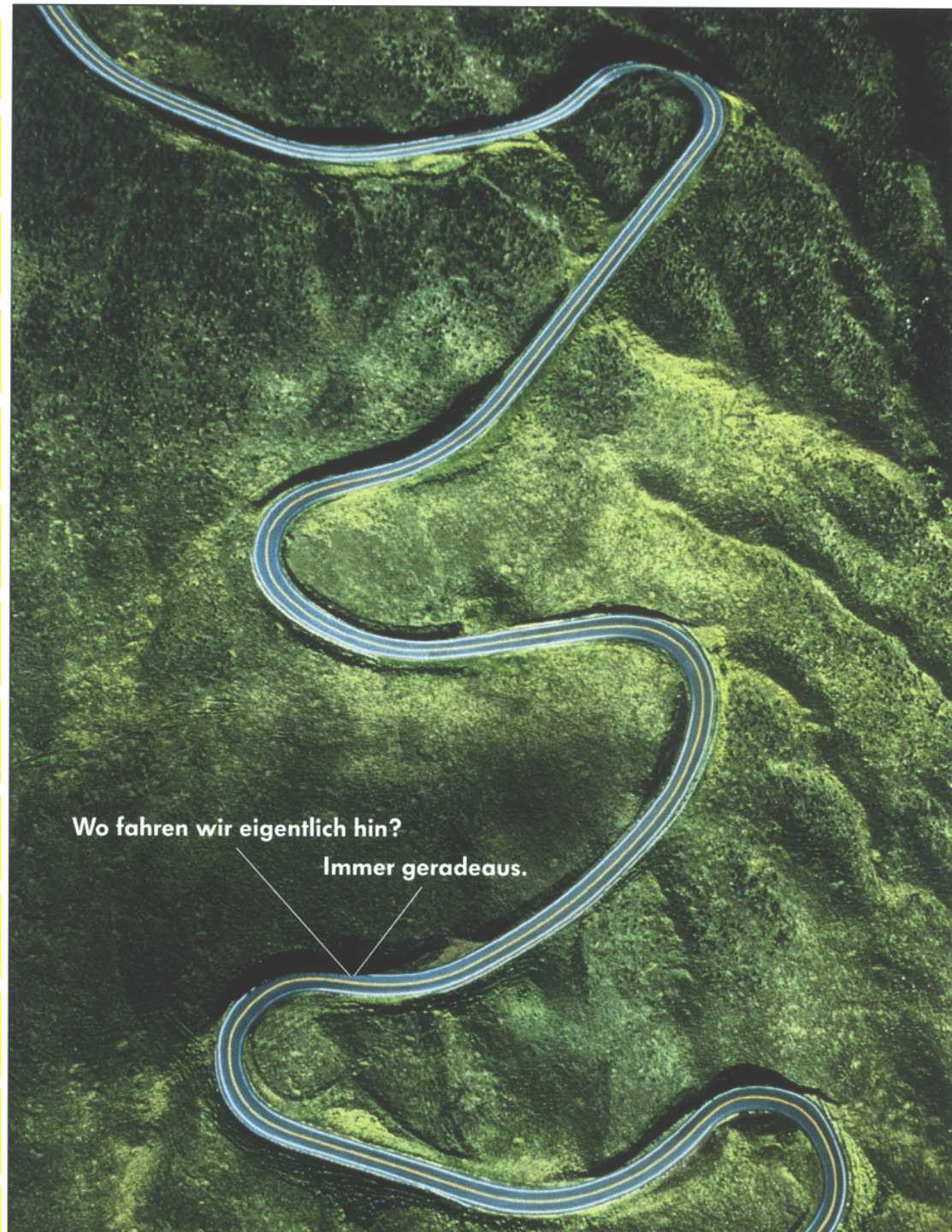 - resolved to contextual descriptions

spatial linguistic semantics

spatial situation

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- ‘vagueness’ is a feature not a bug

- language is only ‘vague’ in particular, very well specified ways, defining parameters for variation

Wo fahren wir eigentlich hin?

Immer geradeaus.

This gives us a semantics, what about contextualisation?

- How can the undesirable readings be ruled out?

    - first, fold in an appropriate semantics for 'fits in'

    - then, apply *qualitative spatial reasoning* to the resulting configurations

Flexible contextualisation

- The semantics of 'fits in' may itself vary considerably according to context

- Abductive hypothesis of a semantics may be used to constrain the anaphoric reference

- But the 'operations' that must be applied to it together with the interpretations for 'large', 'small', etc. are already fixed.

Example

- Always adopt the simplest possible semantics *compatible with the task*...

  - 'fits in' : Spatial Proper Part? (PP):
    RCC5, RCC8

    'Congruent to a part of'? (CGPP)
    MC-4

- Note: this may go wrong
  possibility of exploring psychological processing and mental model construction

Assuming PP:
X *fits-into* Y ↔ PP (X',Y')

- Heuristic:
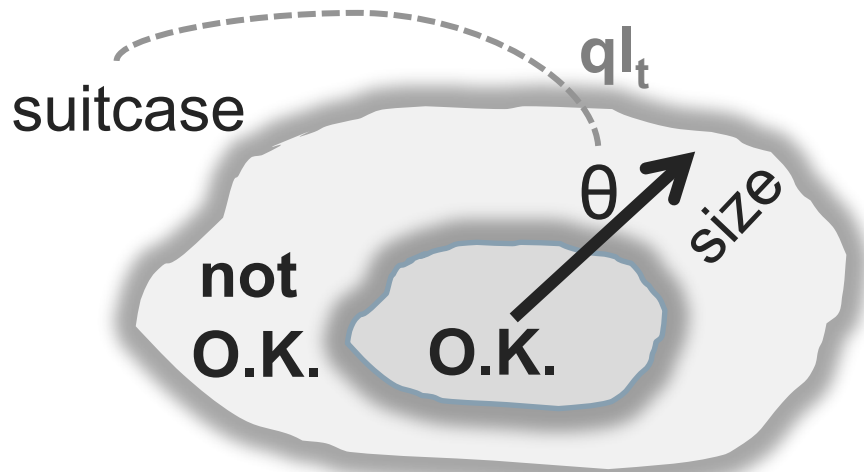 - if a region is a not a proper part of some other region, then making that other region smaller will not change this; similarly, if a region is not a proper part of some other region, then making it larger will not change this.

Bad Case 1

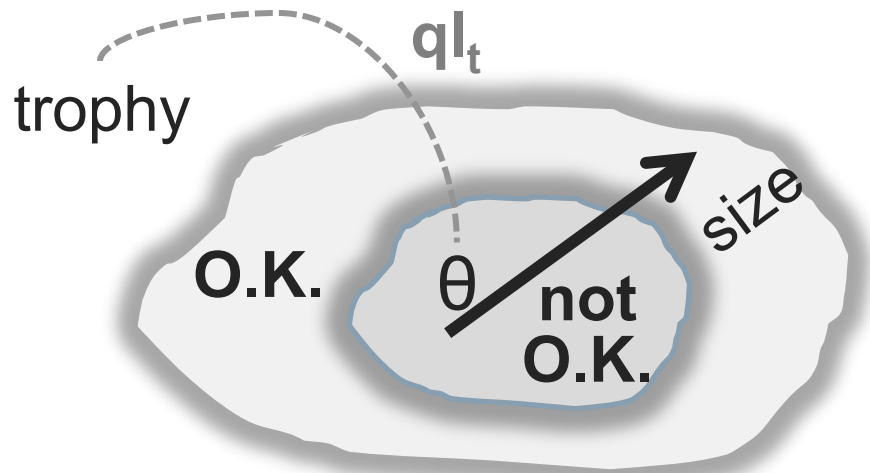trophy cannot fit in suitcase
because suitcase is too large

suitcase

ql$_t$

θ

size

**not
O.K.**

O.K.

**but at the
same time**

$\neg PP(trophy', suitcase')$

changing the size of the suitcase in the direction
indicated will not effect a change in the PP status

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Bad Case 2

trophy cannot fit in suitcase
because trophy is too small

ql_t

trophy

size

O.K.

θ

not
O.K.

**but at the
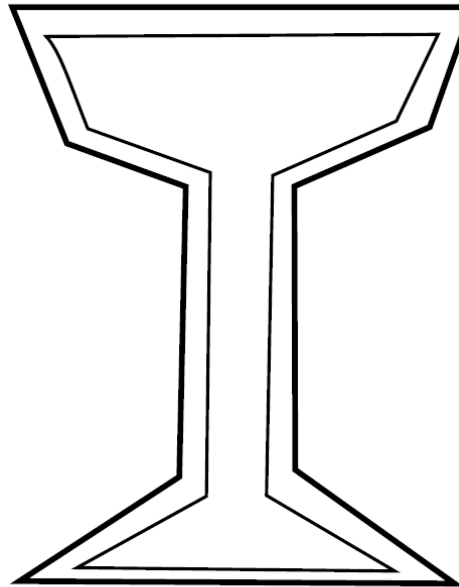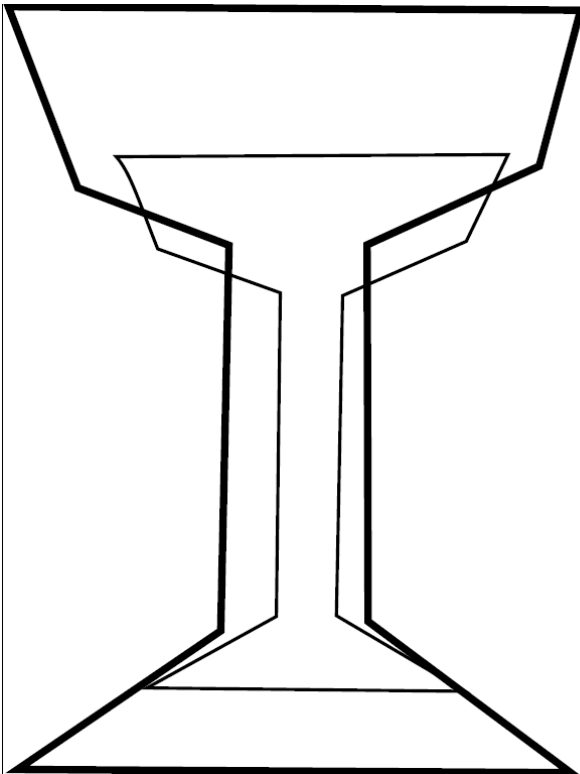same time**

$\neg PP(trophy', suitcase')$

Naïve Reasoning

- This account separates out spatial contextualisations from the linguistic semantics, and may then go wrong

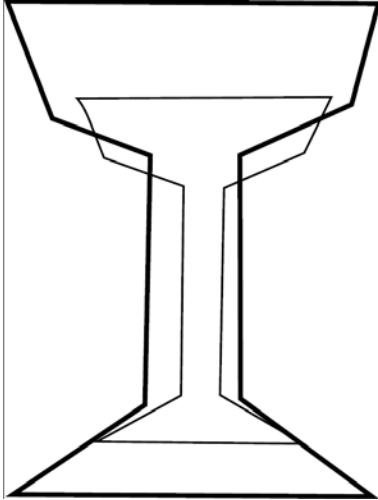# More complex 'case'...
a 'trophy-shaped' suitcase

this is a case where making the suitcase smaller **will** make the trophy fit!

an SCC-reviewer

But...

- what language would go with the first situation?

trophy cannot fit in suitcase
because it is too large

?

trophy cannot fit in suitcase
because the suitcase is too large

?

Flexible contextualisation

- We can force this contextualisation to work
- But it is certainly a dispreferred 'mental' or 'situation' model

- Again:
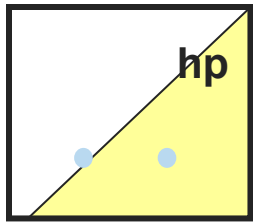 - clear evidence that the semantics of the linguistic component should be separated so as not to over-commit.
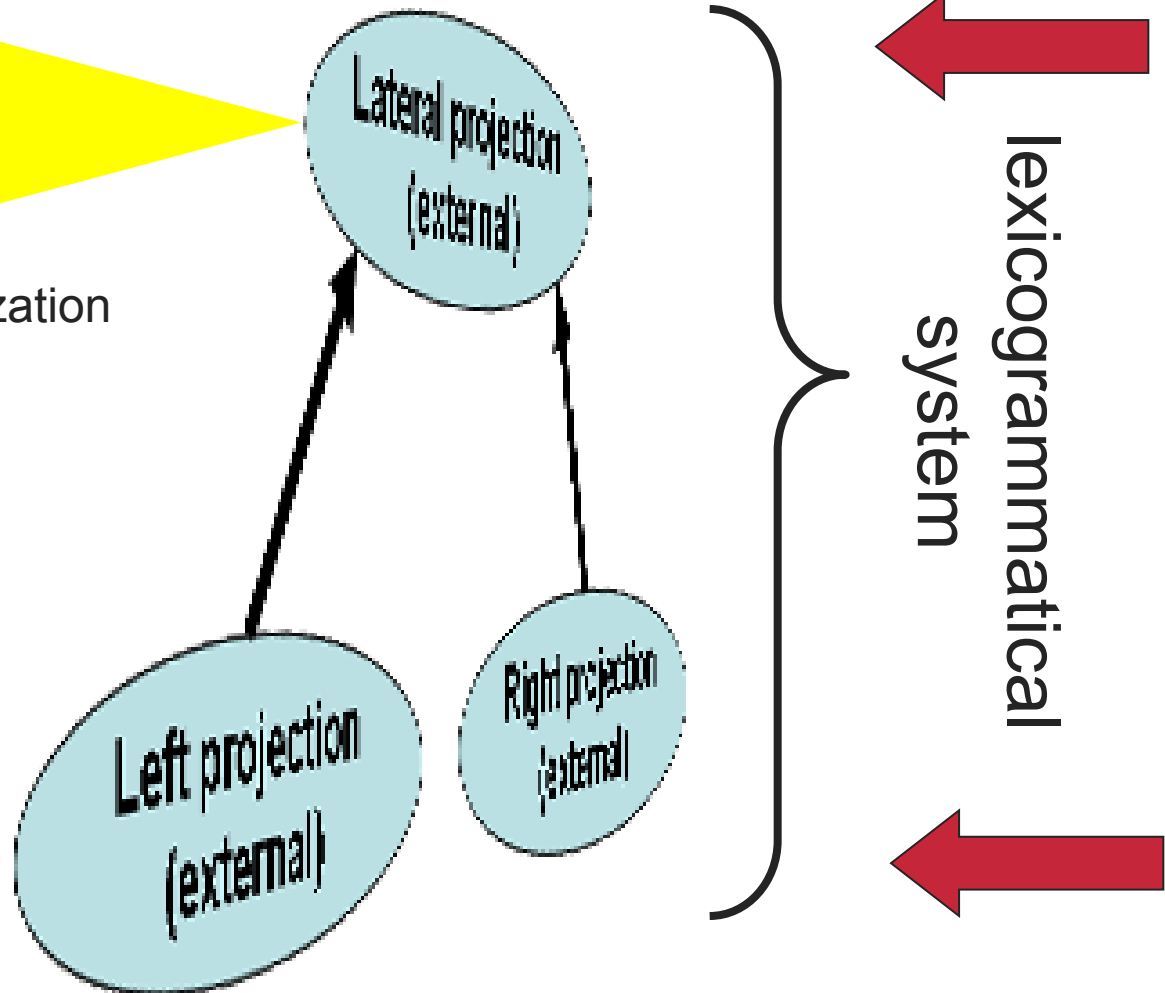
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Interim Conclusion

- Since it is well known that the precise computational and expressive properties of spatial calculi vary considerably depending on precisely which base relations are taken and which entities they operate over, **these differences should be isolated from the linguistic semantics as far as possible**.
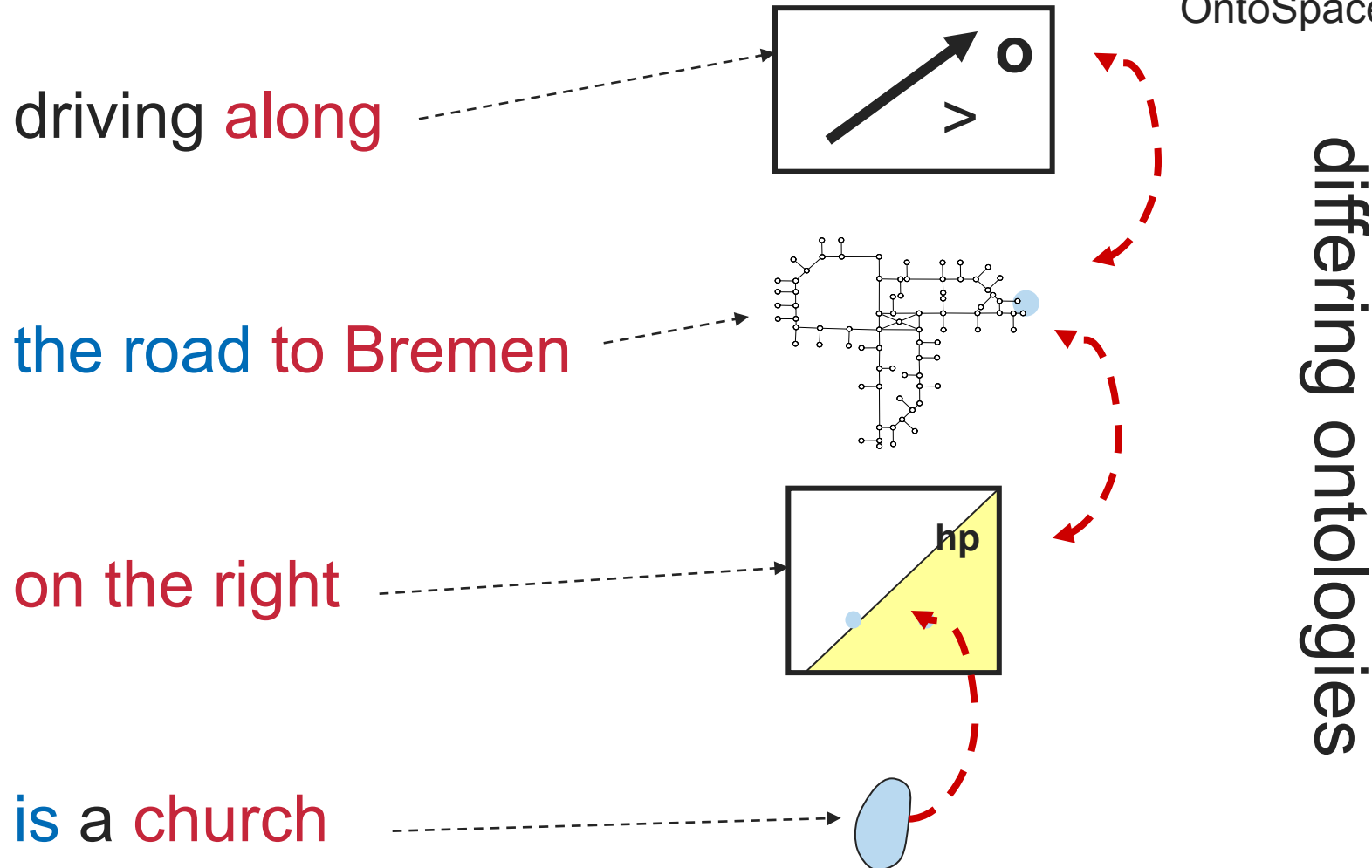
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Linguistic ontology view

hp

details of the axiomatization

Lateral projection (external)

Left projection (external)

Right projection (external)

lexicogrammatical system

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Combining theories
for semantic interpretation

driving along

the road to Bremen

on the right

is a church

differing ontologies

Function of spatial language

- Linguistic constructions serve to combine accounts that draw on many different 'theories' of the world

- A semantic description can aim at revealing what the **minimal commitments** of those linguistic constructions are

Conclusions and Way Forward

- Space, Time and Language:
  many groups, many disciplines, many methods:
  too little interaction: need more

- Challenges from language:
  what kinds of phenomena?
  many standard examples:
  but what is the response to them?

- An analytic architecture for **integrated** yet **heterogeneous** research into space

With thanks...

- to the SFB/TR8 Language and Ontology Team

- & to you...

- Bateman, J. A. (2010), 'Situating spatial language and the role of ontology: issues and outlook', *Linguistics and Language Compass*

- Bateman/Hois/Ross/Tenbrink (2010)
A linguistic ontology of space for natural language processing. *Artificial Intelligence*, 174(14):1027–1071.

- Bateman,J.A. (forthcoming), 'Space, Language and Ontology: A Response to Davis. *Spatial Cognition and Computation*, 2012

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