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Towards Modeling Conceptual Dependency Primitives with Image Schema Logic

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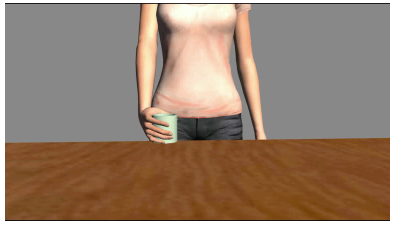
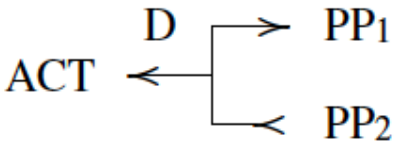
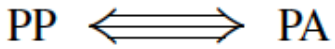
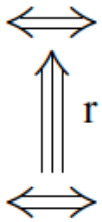
Image Schemas (IS)

Image schema is “a recurring dynamic pattern of our perceptual interaction and motor programs that gives coherence and structure to our experience” (Johnson 1987, xiv)

Image Schema	Physical Experience	Metaphor	Example
CONTAINMENT		CONTAINER FOR CONTAINED	go for a glass, the whole town participated
PATH		LIFE IS A JOURNEY	to be on track, career path, life path

Conceptual Dependency (CD)

Conceptual dependency is a “theory of human natural language understanding” (Schank 1972, 552) and provides a “representation of the conceptual base that underlies all natural language (Schank 1972, 554).

CD Construct	Description
	A picture producer (PP; physical object) is in a two-way dependency relation with an ACT (conceptual primitive done by actor to an object or events that can happen to an object).
	Conceptualization with a direction case (PP2 = origin; PP1 = destination).
	Picture aider (PA) describe PPs and are state predicates that take the form STATE(VALUE), e.g. CONTAIN(x)
	Result causation connective that indicates that one event or act resulted in another.

CD primitives

Conceptual dependency (CD) has numerous primitives used to represent thought, perception, social interaction, and communication. Our focus: physical, spatial, and object-defining primitives.

CD Primitive	Description	Example
PTRANS	A person, object, or thing changes physical position or location.	"Matthew flew come from LA." Matthew ⟺ PTRANS
INGEST	A change in spatial relationship between two picture producers (PP1 and PP2) beginning with PP1 being on the outside of PP2, and ending with PP1 being on the inside of PP2.	"Amy took a deep breath." Amy ⟺ INGEST

IS vs. CD

- spatio-temporal relationships connecting sensorimotor experiences with high-level conceptualization
- objective: inventory of structures to organize meaning at more abstract levels of cognition in form of metaphorical projections
- abstract, gestalt structures, non-propositional

- conceptual basis, i.e., conceptual dependency primitives, with concepts and relations that is interlingual
- objective: map compositional varieties of natural language sequences onto abstract, unambiguous base forms (CD primitives)
- abstract, conceptual, propositional

abstract representation of physical experiences

Existing mapping

CD Primitive	Related Image Schema(s)	Related Spatial Primitives
PTRANS	SOURCE_PATH_GOAL	SOURCE, GOAL, PATH, MOVE, DIRECTION
MOVE	SOURCE_PATH_GOAL, PART-WHOLE	SOURCE, GOAL, PATH, MOVE, DIRECTION, PARTS, WHOLE,
GRASP	SUPPORT	ATTRACTION, COMPULSION
PROPEL	FORCE	CONTACT
INGEST	SOURCE_PATH_GOAL, CONTAINMENT, FORCE	IN, BOUNDARY, CONTAINER, SOURCE, GOAL, PATH, MOVE, DIRECTION
EXPEL	SOURCE_PATH_GOAL, CONTAINMENT, FORCE	OUT, BOUNDARY, CONTAINER, SOURCE, GOAL, PATH, MOVE, DIRECTION
PP	OBJECT	
PART	PART-WHOLE	PARTS, WHOLE, CONFIGURATION
CONTAIN	CONTAINMENT	CONTAINER, IN, OUT, BOUNDARY

(Macbeth et al. 2017)

Crowdsourcing

- Replicating a crowdsourcing experiment conducted for CD (Macbeth and Barionnette 2016) for image schemas (Gromann and Macbeth 2019) with the same set of sentences
- Compare CD primitives and image schemas utilized to annotate the same sentence
- Largely confirmed expert mapping of CD and IS

Motivation

- Based on this previous mapping, utilize image schemas and more specifically an existing Image Schema Logic (ISL^{M}) to formalize CD primitives

- Goal of CD: provide minimal set of necessary abstract constructs, “conceptualizations”, to capture meaning in natural language => we want to contribute by checking current physical CD primitive inventory based on formalization for consistency and overlap

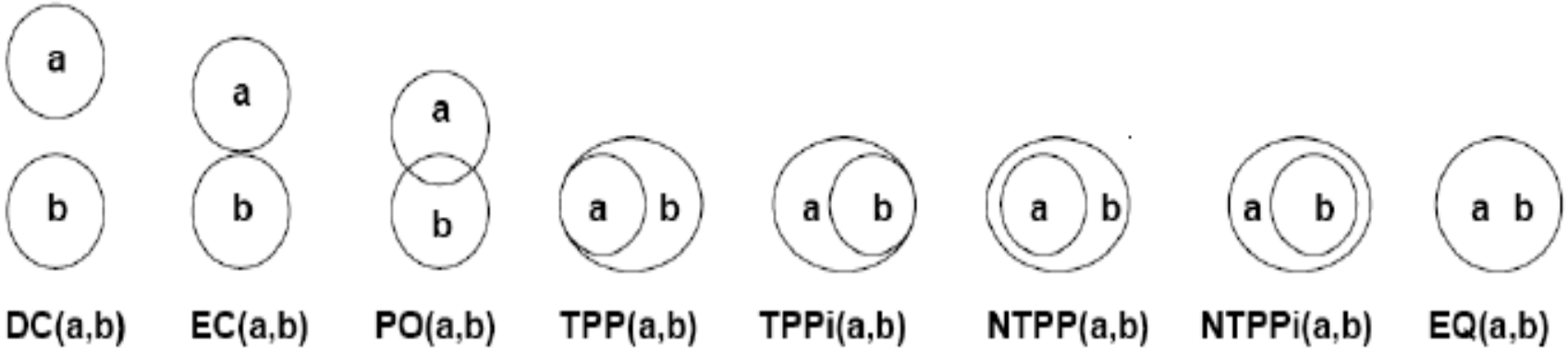
Image Schema Logic (ISL^M)

Three dimensions required to capture image schemas:

- Spatial
- Movement
- Temporal

Spatial ISL^{M}

- Regional Connection Calculus 8 (RCC-8) (Randell et al. 1992)



Movement ISL^{M}

- Qualitative Trajectory Calculus (QTC) (Van de Weghe et al. 2006)
  - Simplified as:

Move towards $O_1 \rightsquigarrow O_2$

Move away from $O_1 \hookleftarrow O_2$

No relative movement $O_1 \,|\circ\, O_2$

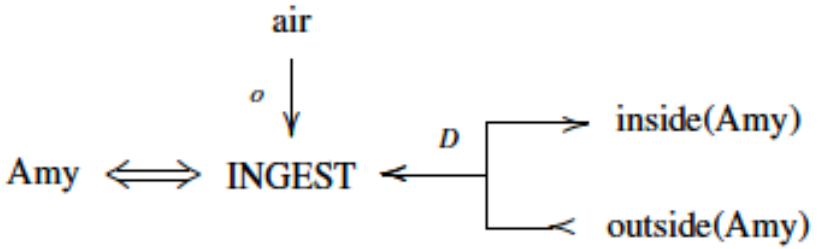
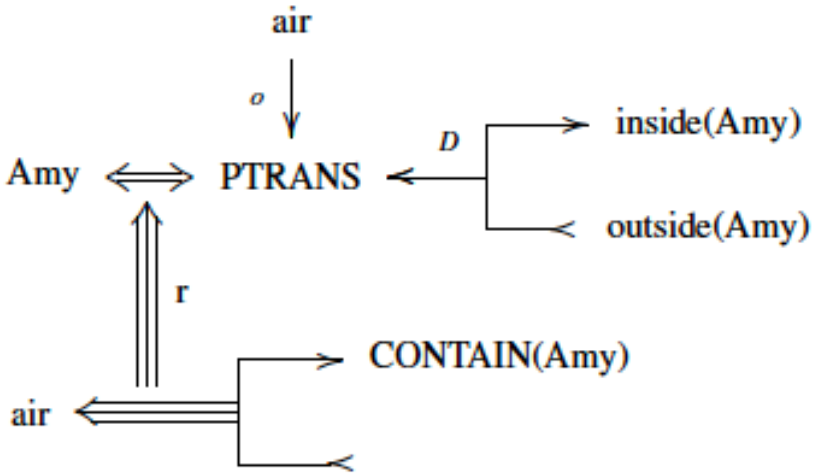
Temporal ISL^{M}

- Linear Temporal Logic (LTL)
  - $F\varphi$ (at sometime in the future, φ) is defined as $\top U \varphi$,
  - $G\varphi$ (at all times in the future, φ) is defined as $\neg F \neg \varphi$.

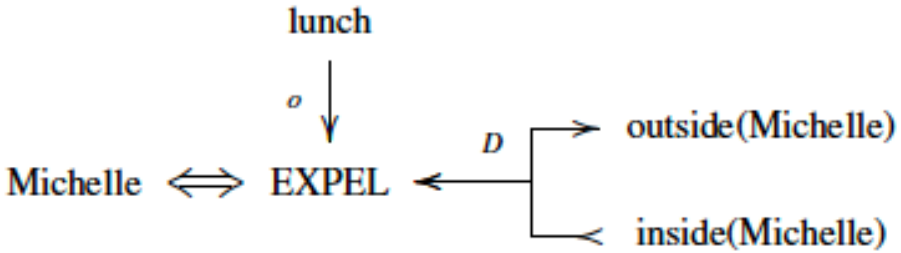
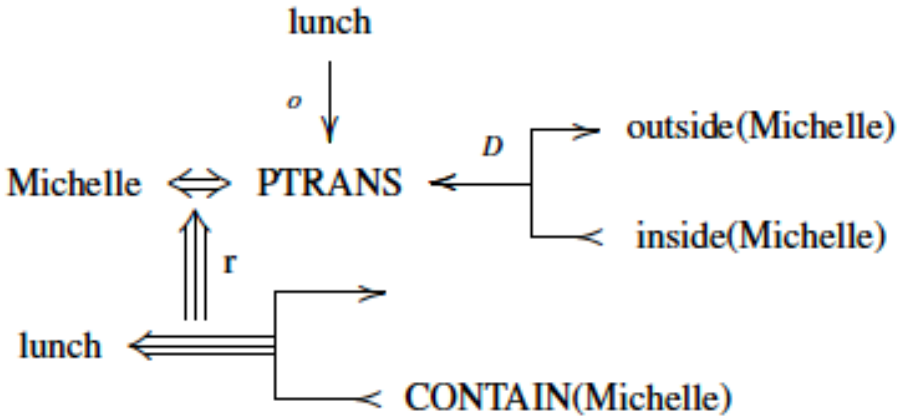
Modeling CD primitives in ISL^M

CD Primitive	ISL^M
PTRANS	$\text{On\_PATH\_Toward}(O_1, O_2) :=$ $(O_1 \rightsquigarrow O_2 \wedge DC(O_1, O_2))$	$\text{On\_PATH\_From}(O_1, O_2) :=$ $(O_1 \hookleftarrow O_2 \wedge DC(O_1, O_2))$
MOVE	$\text{Move\_Toward}(O_1, O_2, O_3) :=$ $PP(O_1, O_2) \wedge$ $\text{On\_PATH\_Toward}(O_1, O_3)$	$\text{Move\_From}(O_1, O_2, O_3) :=$ $PP(O_1, O_2) \wedge$ $\text{On\_PATH\_From}(O_1, O_3)$
CONTAIN	$\text{Contained\_Inside}(O_1, O_2) :=$ $\text{inside\_of}(in, O_2) \wedge PP(O_1, in)$	$\text{Crossing\_Opening}(O_1, O_2, opening) :=$ $\text{opening\_of}(opening, O_2) \wedge$ $(DC(O_1, O_2) \wedge \text{On\_PATH\_Toward}(O_1, opening)) \wedge$ $\mathbf{F}(PO(O_1, opening))$

INGEST in ISL^M

CD Diagram	ISL^M
	$Going\_In(air, Amy, mouth) :=$ $Crossing\_Opening(air, Amy, mouth) \wedge$ $\mathbf{F}(Contained\_Inside(air, Amy))$
	$Going\_In(air, Amy, mouth) :=$ $Crossing\_Opening(air, Amy, mouth) \wedge$ $\mathbf{F}(Contained\_Inside(air, Amy))$

EXPEL in ISL^M

CD Diagram	ISL^M
	*Going_*OUT(*lunch*,*Michelle*,*mouth*) := Contained_Inside(*lunch*,*Michelle*)∧ F(Crossing_Opening (*lunch*,*Michelle*,*mouth*)∧ F(outside_of(*lunch*,*Michelle*)))
	*Going_*OUT(*lunch*,*Michelle*,*mouth*) := Contained_Inside(*lunch*,*Michelle*)∧ F(Crossing_Opening (*lunch*,*Michelle*,*mouth*)∧ F(outside_of(*lunch*,*Michelle*)))

Observations

- EXPEL and INGEST (CD) are special cases of CONTAINMENT and SOURCE_PATH_GOAL (IS)
- represent a composition of PTRANS, CONTAIN, and DIRECTION
- potential to reduce the number of CD primitives in the inventory utilized to abstractly formalize natural language meaning

Conclusions

- Abstract formalization facilitates the mapping between two cognitive meaning representation theories
- and the checking of the consistency and potential redundancies in the inventory of CD primitives
- ISL^{M} and its dimensions are adequate to model physical, spatial, and object-defining CD primitives - how about other CD primitives?

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